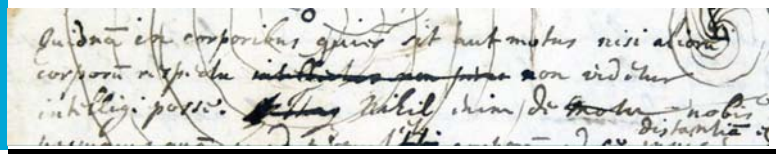


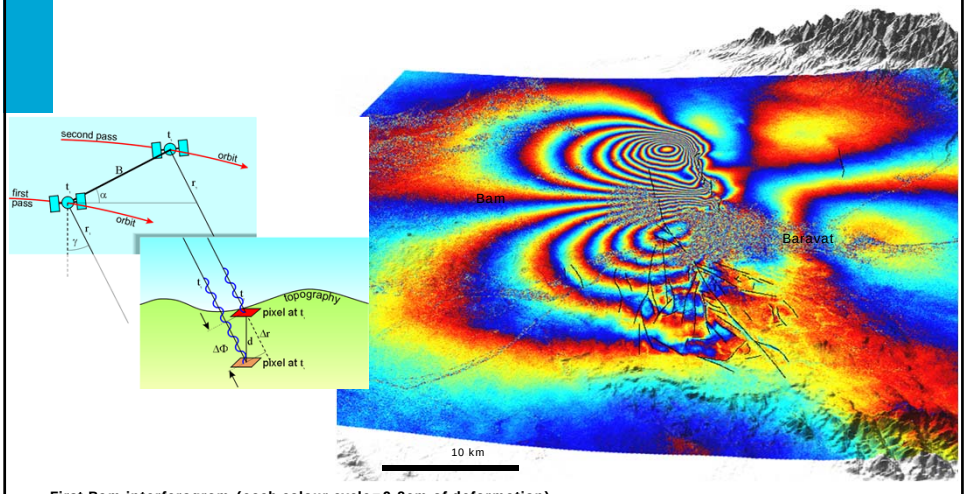
Satellite radar interferometry for operational geodesy:
a SWOT analysis

Ramon Hanssen

Delft University of Technology
r.f.hanssen@tudelft.nl

Workshop 'the Dark Side of Remote Sensing', BELSPO, CSL, RMCA, ECGS, Brussel, 9 December 2015

Conventional 2-pass InSAR



First Bam interferogram (each colour cycle=2.8cm of deformation)

Constructed from Envisat ASAR data, ESA

The InSAR SWOT:

Strengths, Weaknesses, Opportunities, Threats

- The *Engineering Geodesy* perspective, instead of a *geophysical* perspective (accountability)
- Towards an operational system: *monitoring* instead of *case studies*
- Emphasis on *what is needed* instead of *what is possible*

STRENGTHS, weaknesses, opportunities, threats

- **Strengths** by example:
  - Nation-wide elevation and elevation-change
  - Oil/Gas
  - Rail
  - Urban
  - Pipes
  - Road

The Dynamic DEM (D-DEM)

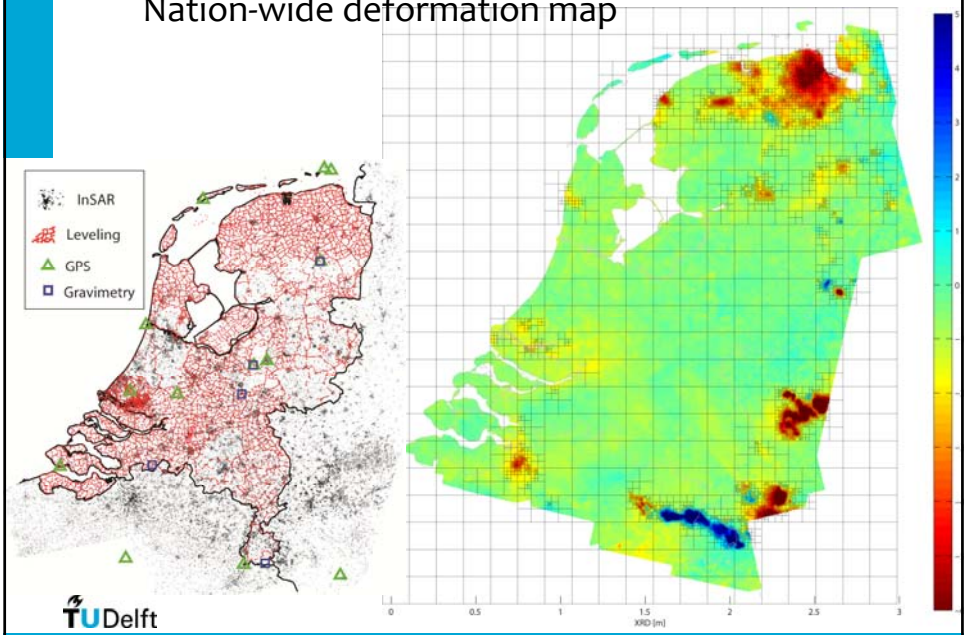
- National height model of the Netherlands: “AHN”:

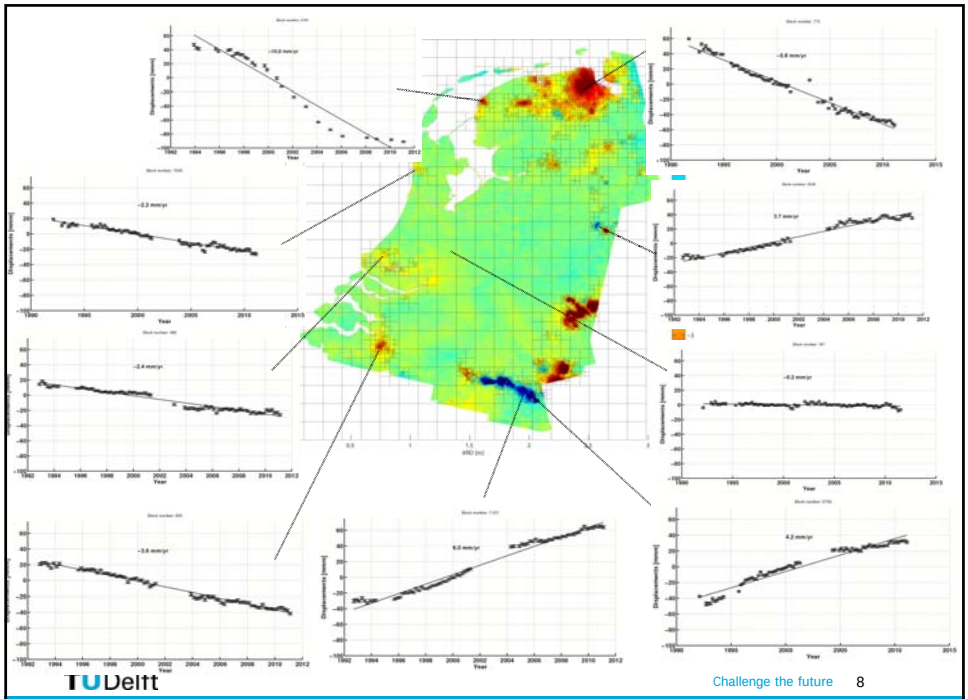
  the *Actual Height Model*

AHN-1, AHN-2, AHN-3

5 cm precision, 30cm posting

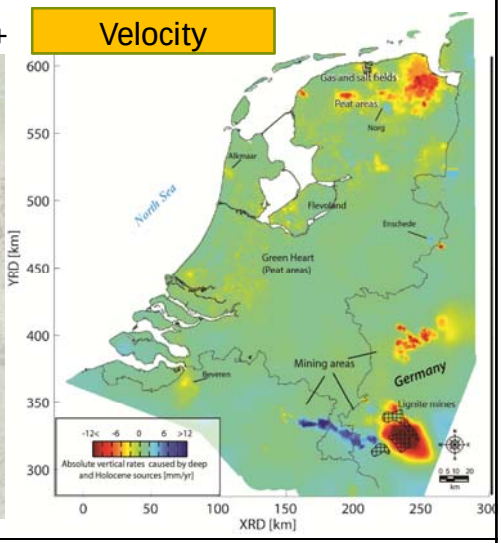
Deformation of the Rhine-Meuse-Scheldt delta
Nation-wide deformation map



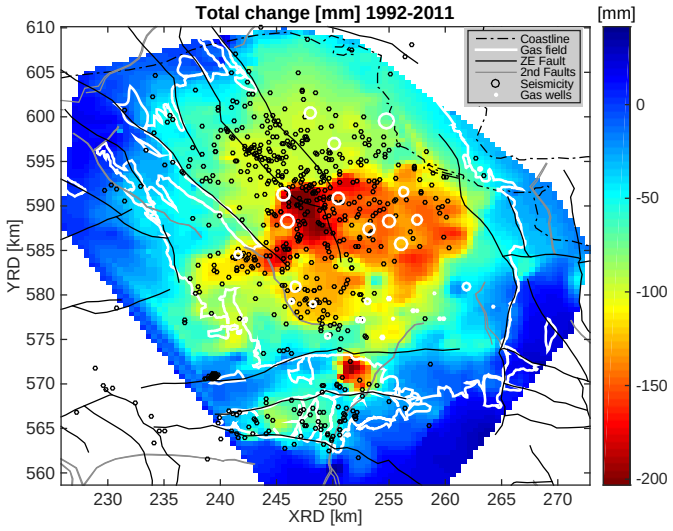


The Dynamic DEM

Elevation + Velocity

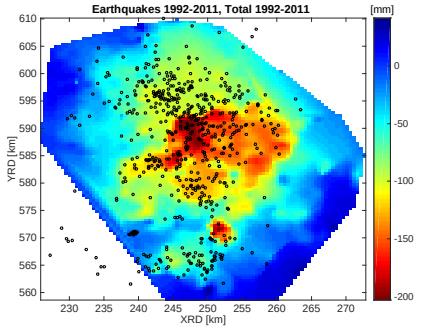


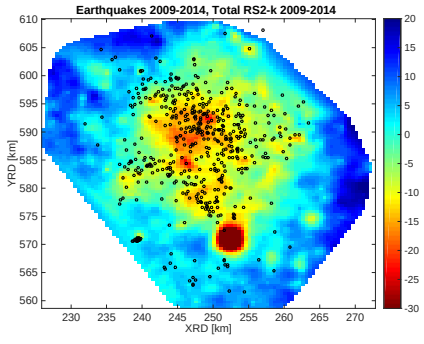
Oil & Gas: relation to induced seismicity
subsidence, faults, wells and earthquakes



Oil & Gas: relation to induced seismicity

Variation over time, dependent on production





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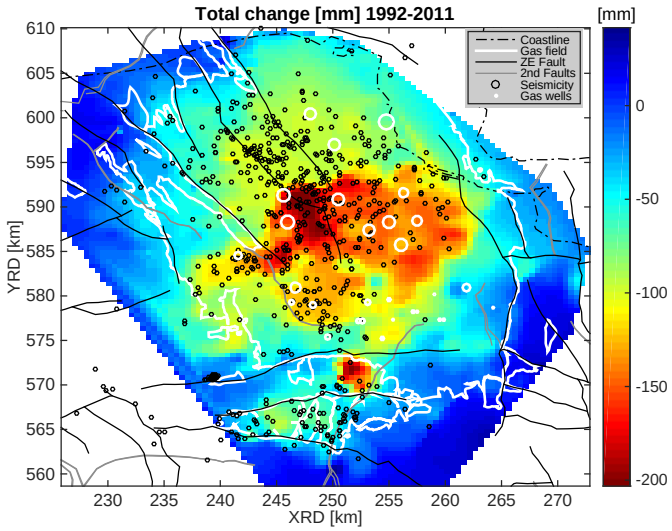
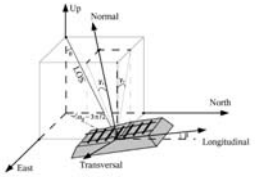
Strengths, Weaknesses, Opportunities, Threats

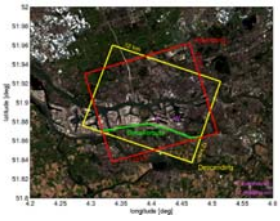
Gradient from Cumulative Deformation

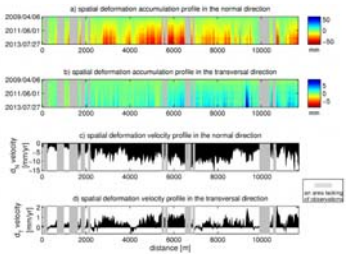


Rail infrastructure

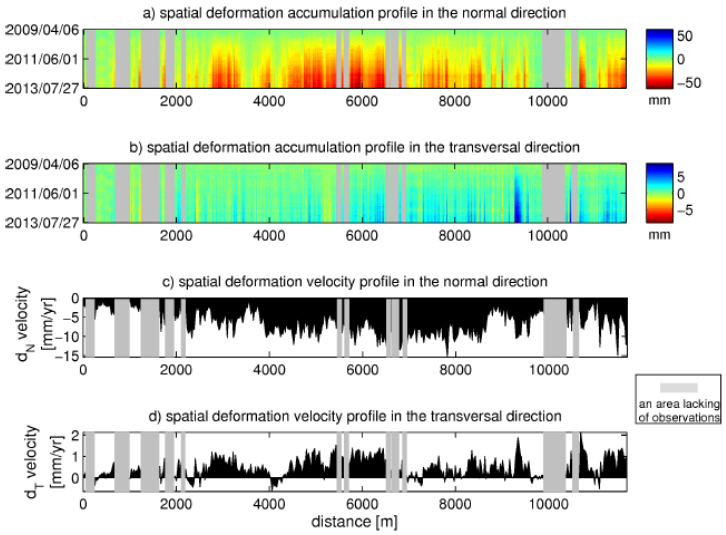
- Railways need to be monitored, especially with high speed trains
- Decomposition in normal and transversal deformation

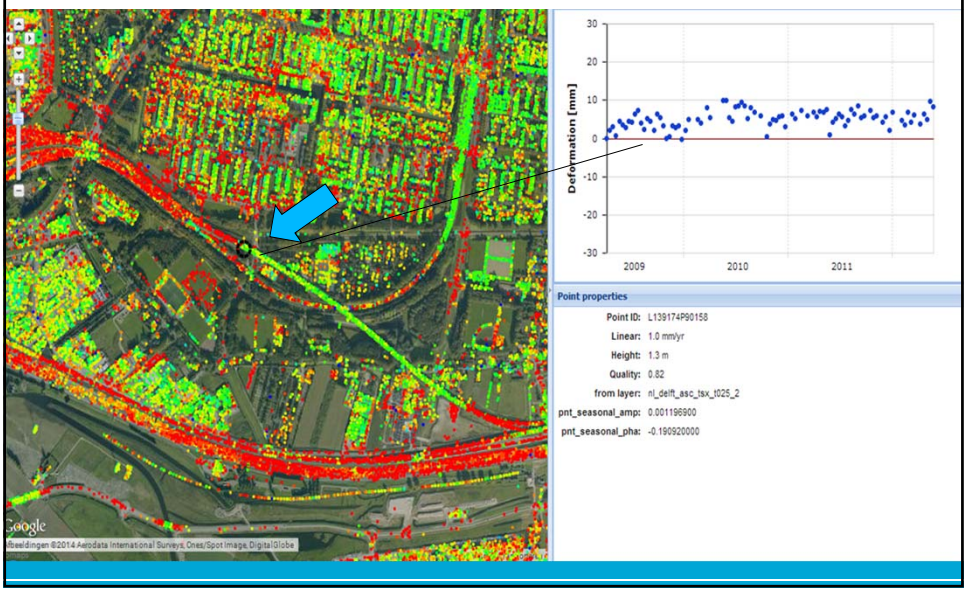


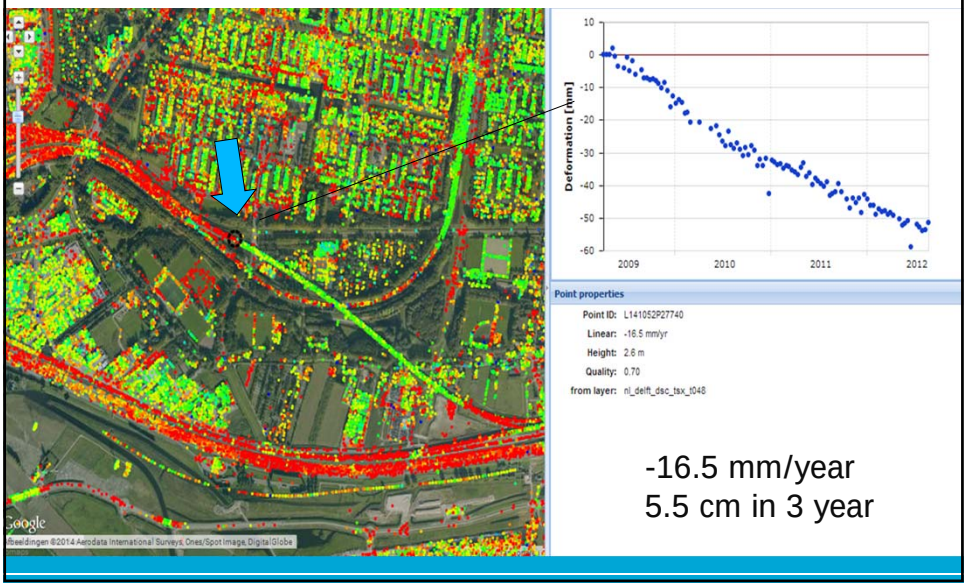


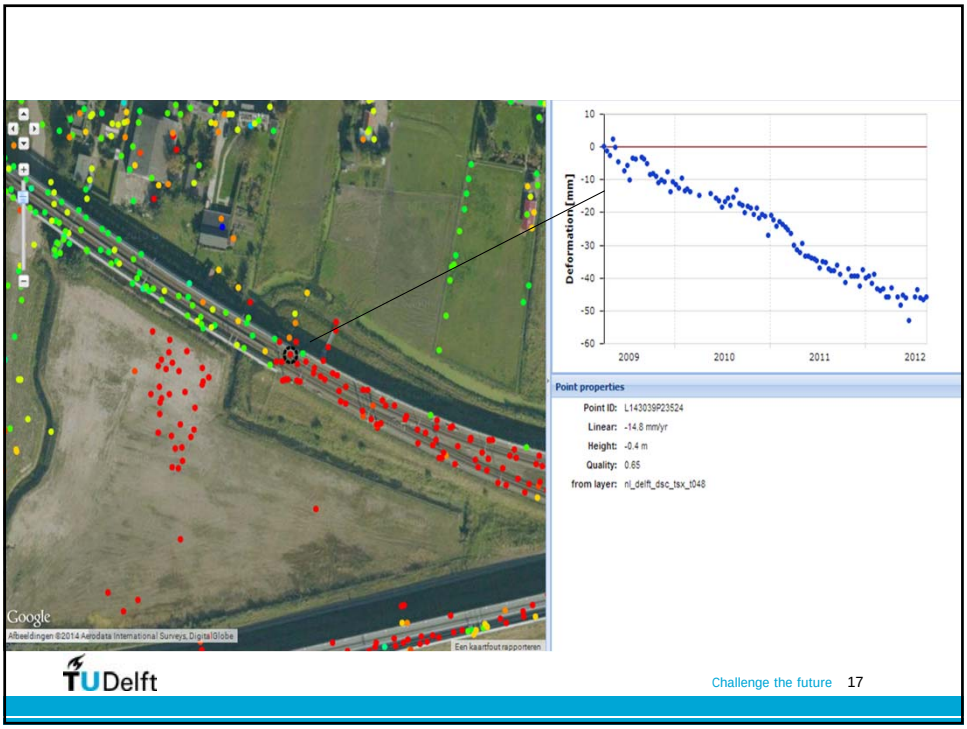


Chang et al, Int. J. Railway Technology, 2014


a) spatial deformation accumulation profile in the normal direction
2009/04/06
2011/06/01
2013/07/27
0
2000
4000
6000
8000
10000
50
0
−50
mm
b) spatial deformation accumulation profile in the transversal direction
5
0
−5
c) spatial deformation velocity profile in the normal direction
d_N velocity [mm/yr]
0
−5
−10
−15
d) spatial deformation velocity profile in the transversal direction
d_T velocity [mm/yr]
2
1
0
distance [m]
an area lacking of observations


Deformation [mm]
30
20
10
0
-10
-20
-30
2009
2010
2011
Point properties
Point ID: L139174P90158
Linear: 1.0 mm/yr
Height: 1.3 m
Quality: 0.82
from layer: nl_delft_asc_tsx_t025_2
pnt_seasonal_amp: 0.001196900
pnt_seasonal_pha: -0.190920000


Deformation [mm]
10
0
-10
-20
-30
-40
-50
-60
2009
2010
2011
2012
Point properties
Point ID: L141052P27740
Linear: -16.5 mm/yr
Height: 2.6 m
Quality: 0.70
from layer: nl_delft_dsc_tsx_t048
-16.5 mm/year
5.5 cm in 3 year


Deformation [mm]
10
0
-10
-20
-30
-40
-50
-60
2009
2010
2011
2012
Point properties
Point ID: L143039P23524
Linear: -14.8 mm/yr
Height: -0.4 m
Quality: 0.65
from layer: nl_delft_dsc_tsx_t048
Google
Afbeeldingen ©2014 Aerodata International Surveys, DigitalGlobe
Een kaartfout rapporteren
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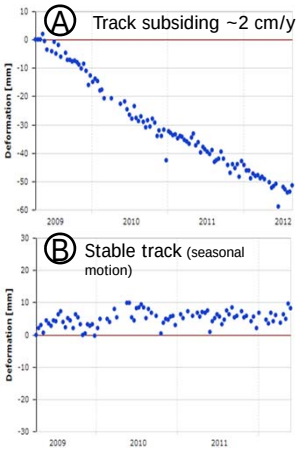
Detecting hazardous deformation

TerraSAR-X

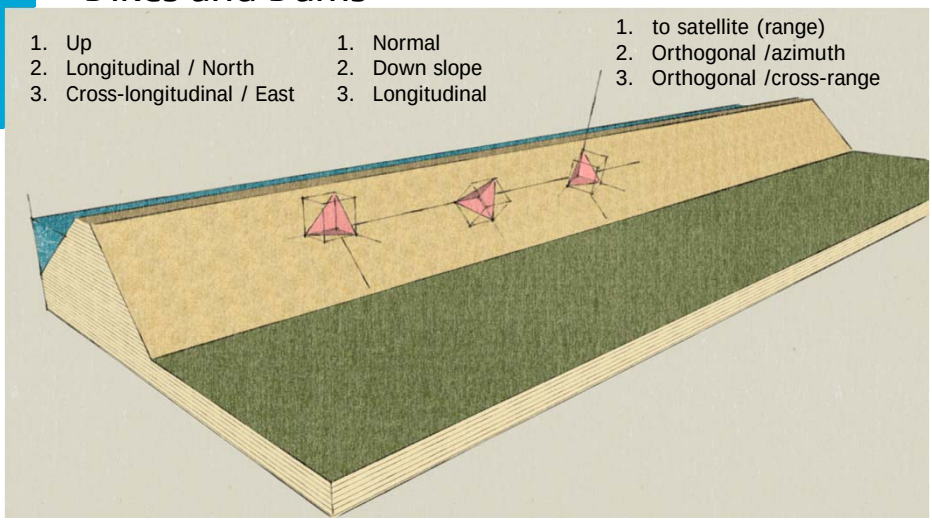


Dikes and Dams

1. Up
2. Longitudinal / North
3. Cross-longitudinal / East

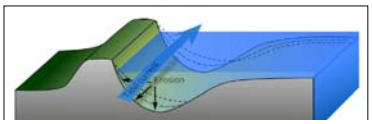
1. Normal
2. Down slope
3. Longitudinal

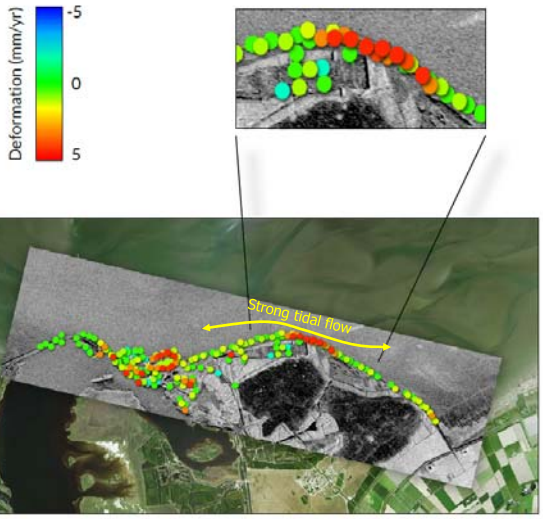
1. to satellite (range)
2. Orthogonal /azimuth
3. Orthogonal /cross-range



Monitoring Lauwersmeer dike (Netherlands)

- ✓Underwater erosion affecting 12km dike
- ✓ Dike had to be reinforced
- ✓global view on deformation processes
- ✓limited extent: 500m length isolated
- ✓early detection





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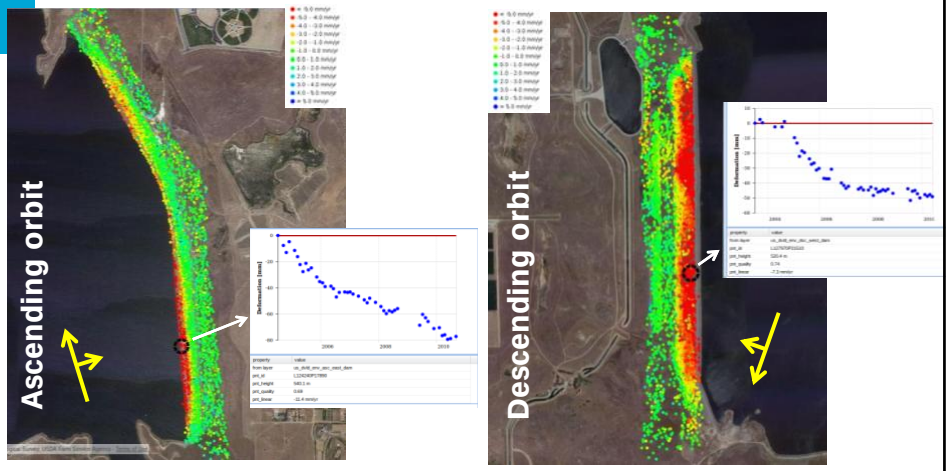
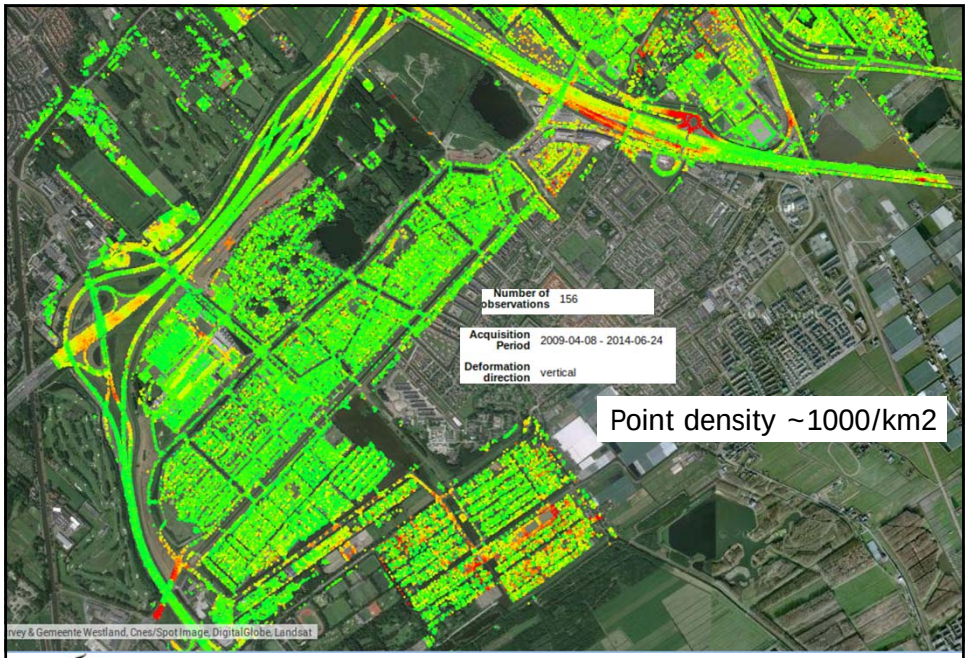
Diamond Valley Lake dam, US

- East and West Dam. 2003-2010 (Envisat)



Chemical installations/ factories

From ‘colored dots’ to solving problems



"High" points

"Low" points

Sewer system with buffer

Sampling within buffer

Ground movement over sewer network

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Strengths, Weaknesses, Opportunities, Threats

Risk map: spatial gradients

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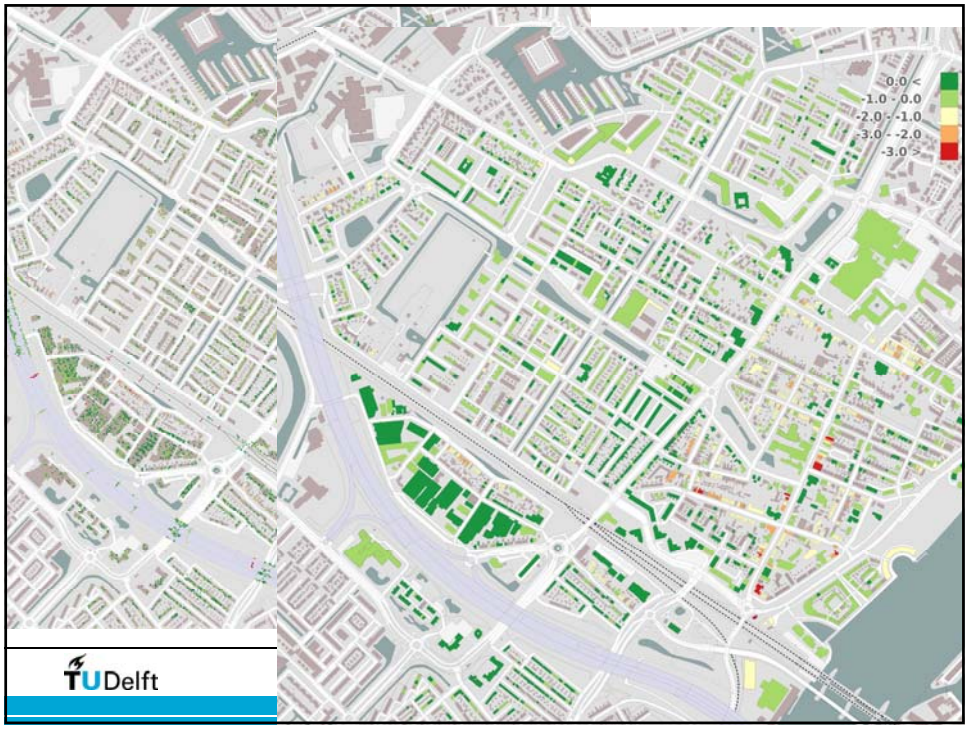
Strengths, Weaknesses, Opportunities, Threats



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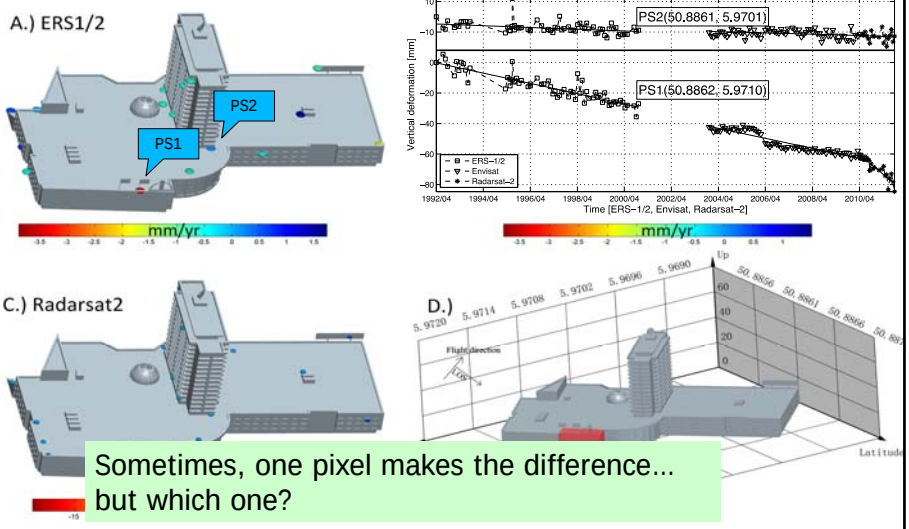
Sinkhole causing collapse of a building



Sometimes, one pixel makes the difference…
but which one?

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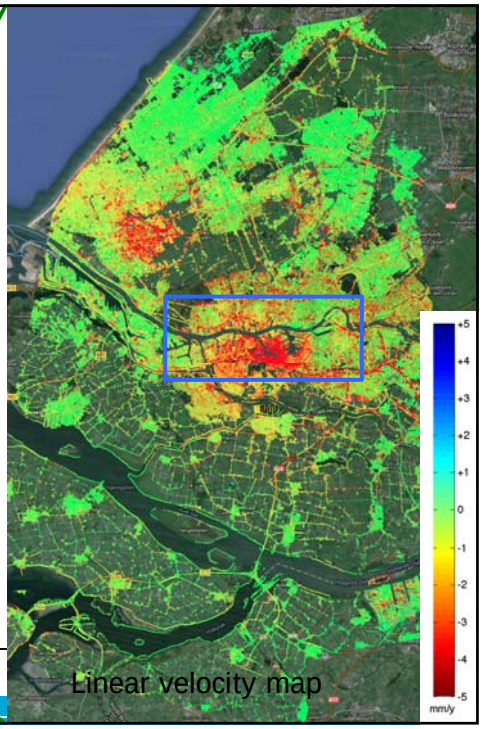
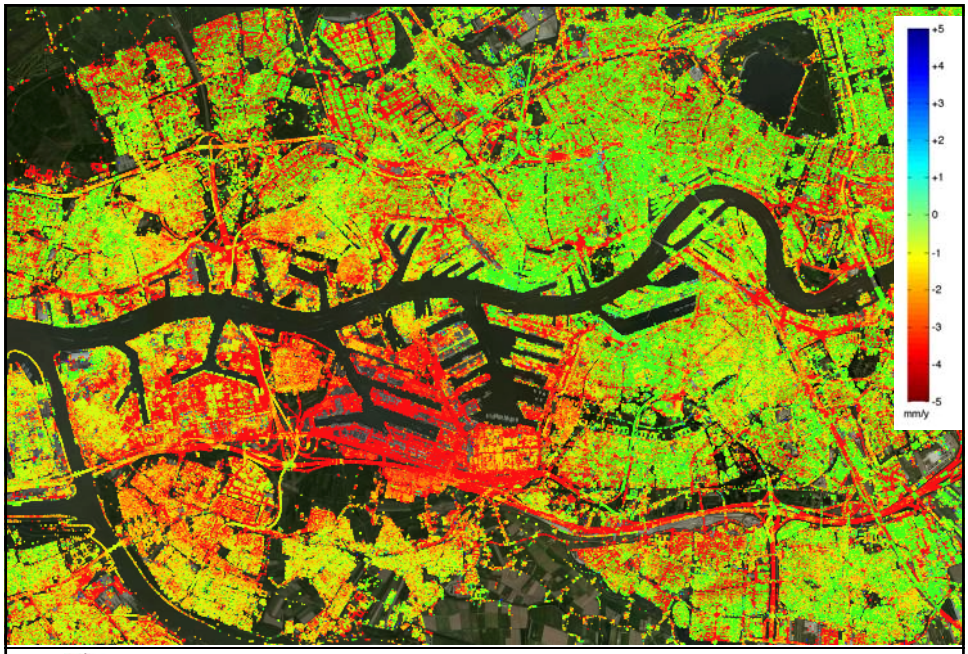
Strengths, **WEAKNESSES**, opportunities, threats

- It's relative! (Rank defect) Interpretation is extremely difficult
- We don't know what we are measuring
- Opportunistic in time and space
- Dependent on land cover
- Quality description inadequate
- How to deal with validation?



Linear velocity map



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Linear velocity map

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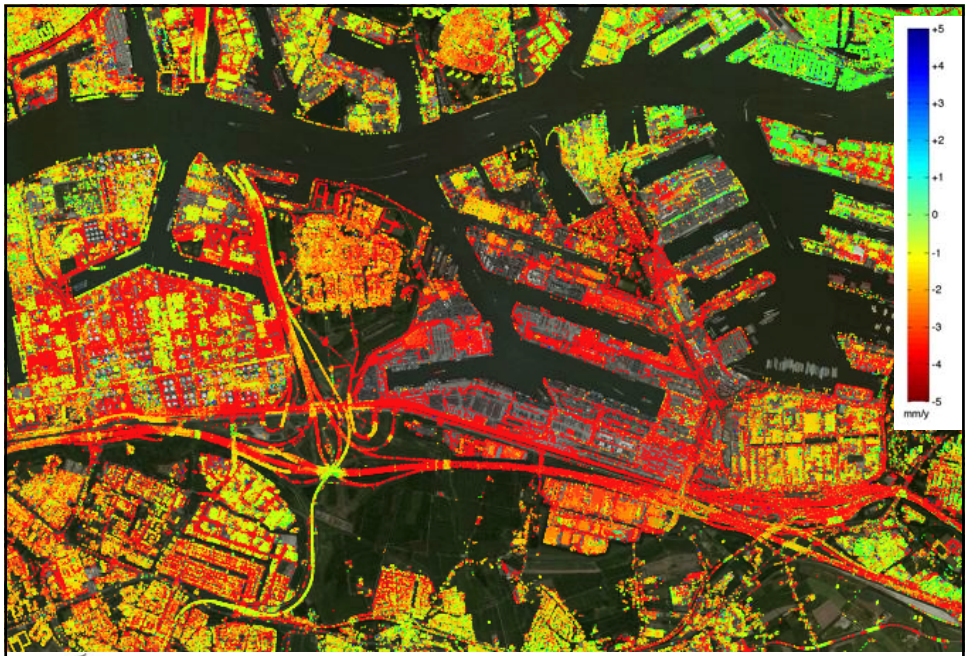
Strengths, **Weaknesses**, Opportunities, Threats



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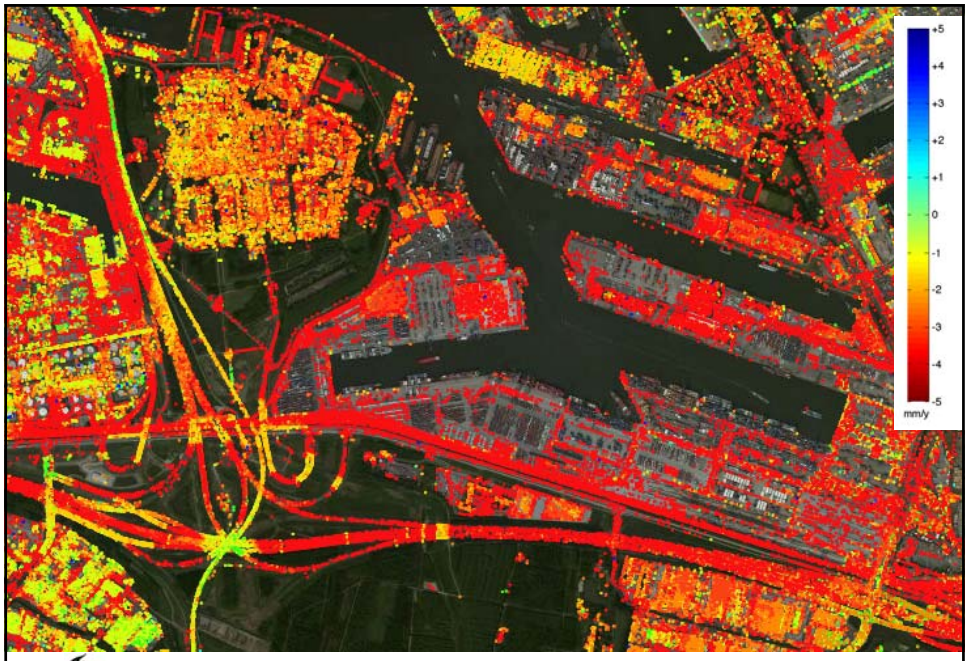
Linear velocity map

Challenge the future 37 Web portal Skygeo

Strengths, **Weaknesses**, Opportunities, Threats



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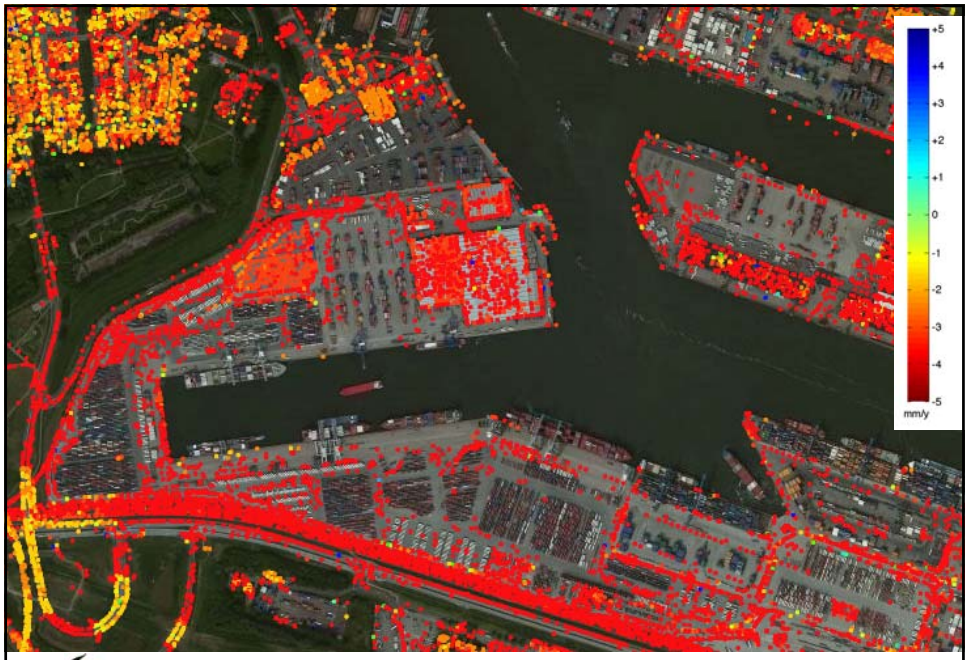
Linear velocity map

Challenge the future

Strengths, **Weaknesses**, Opportunities, Threats



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Linear velocity map

Challenge the future

Strengths, **Weaknesses**, Opportunities, Threats

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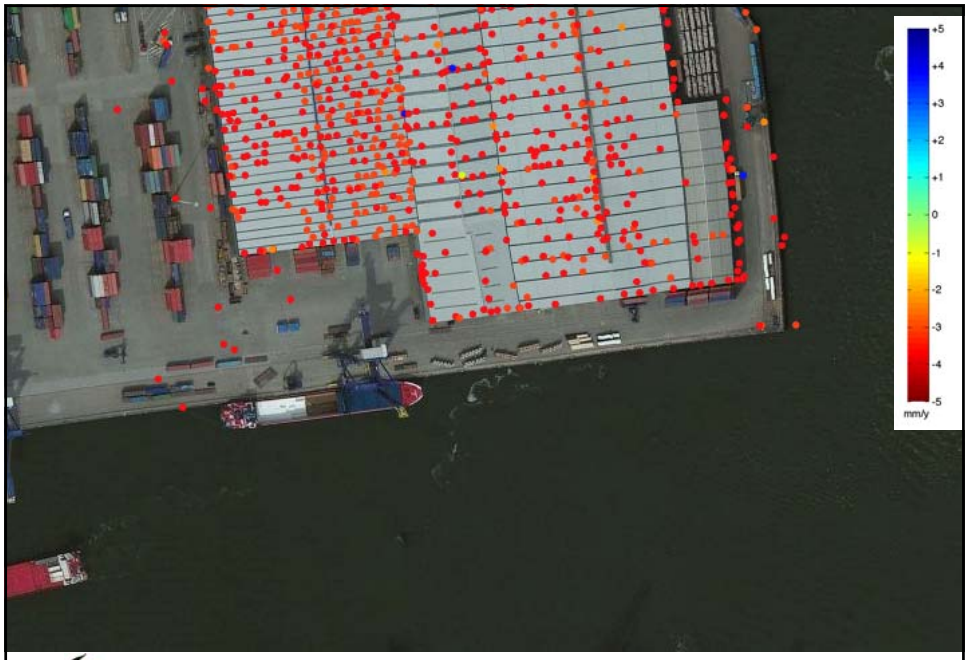
Linear velocity map

Challenge the future 40 Web portal Skygeo

Strengths, **Weaknesses**, Opportunities, Threats



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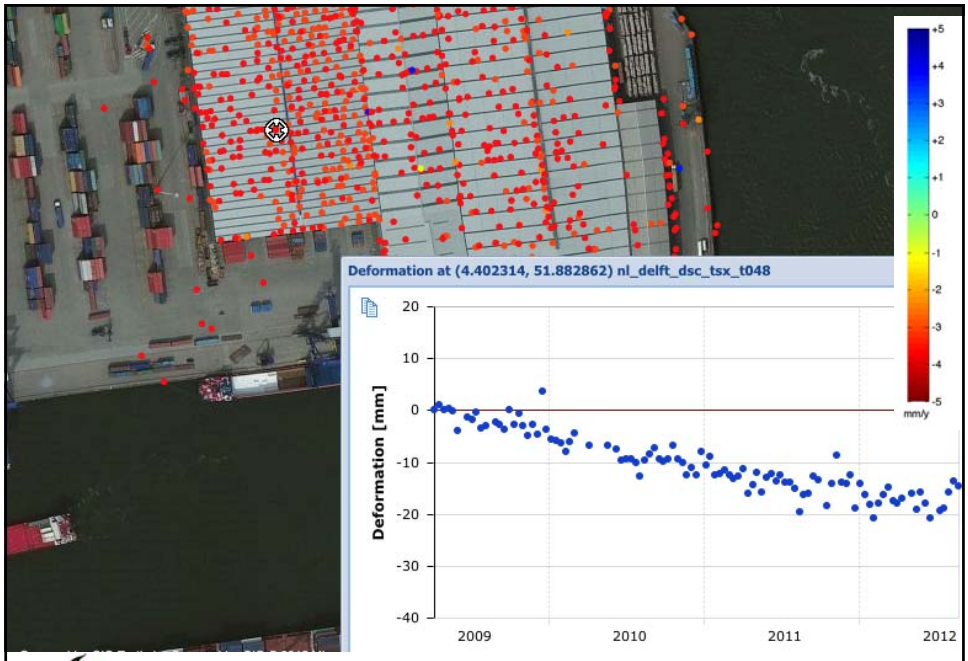
Linear velocity map

Challenge the future 41 Web portal Skygeo

Strengths, **Weaknesses**, Opportunities, Threats



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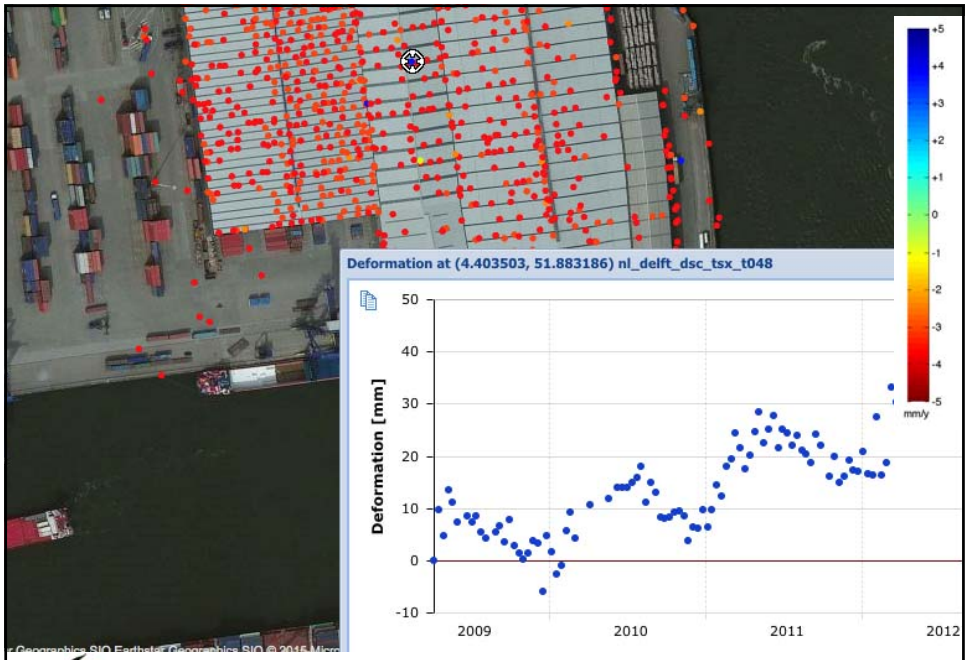
Linear velocity map

Challenge the future 42 Web portal Skygeo

Strengths, **Weaknesses**, Opportunities, Threats



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Linear velocity map

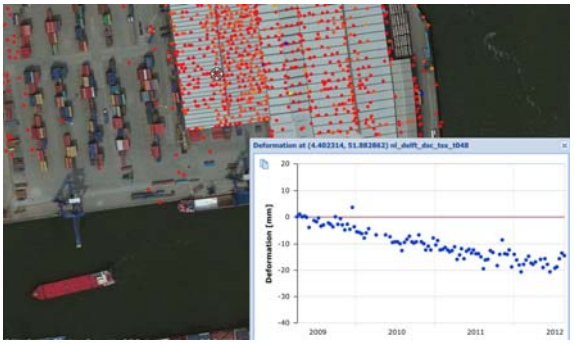
Challenge the future 43 Web portal Skygeo

Strengths, **Weaknesses**, Opportunities, Threats

Frequently asked questions
(a challenge for Engineering Geodesy)

- Can I interpret an InSAR time series?
- What is the precision of InSAR products?
- What is the reliability of InSAR products?
- What am I measuring?
- Which model fits the data best?
- Which data processing method is best?
- Can I compare the results of value-added service provider A with those of provider B?
  - How do we “standardize” InSAR?
  - Are InSAR results refutable?
- If I get a new image, do my estimates change?

Can I interpret an InSAR time series?



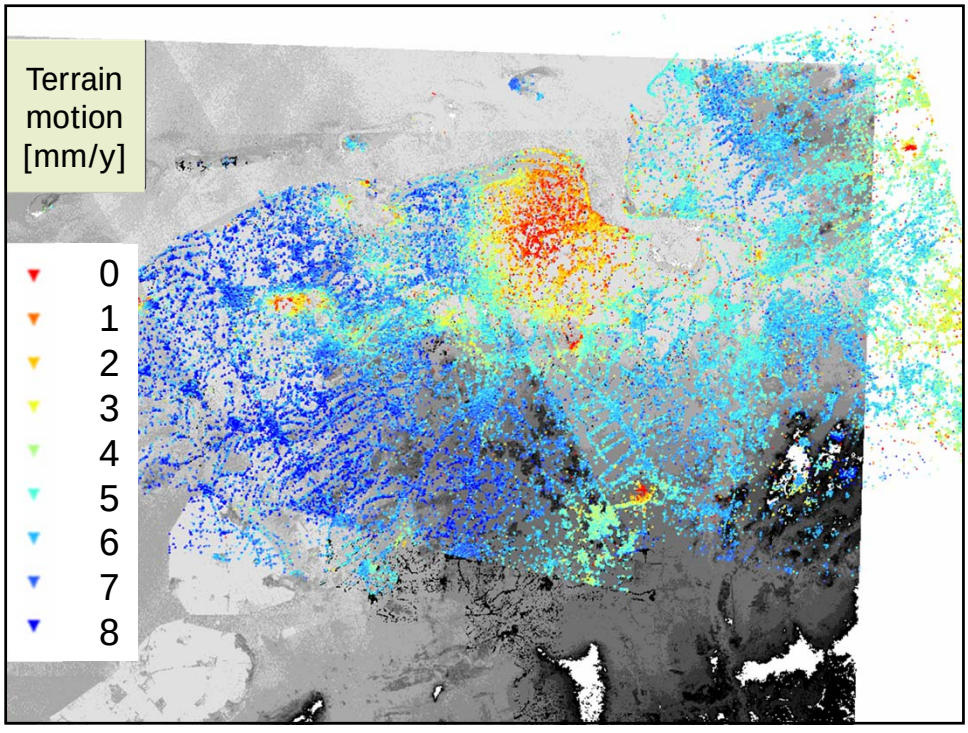
What is this point doing?

Quidnam in corporibus quies sit, aut motus nisi aliorum corporum respectu non videtur intellegi posse

Huygens *(~1650): whether a point is at rest or in uniform motion is not observable.*

Can I interpret an InSAR time series? → Consequence

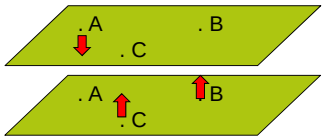
- InSAR time series are in **interval** scale, not **ratio** scale (Steven's taxonomy)

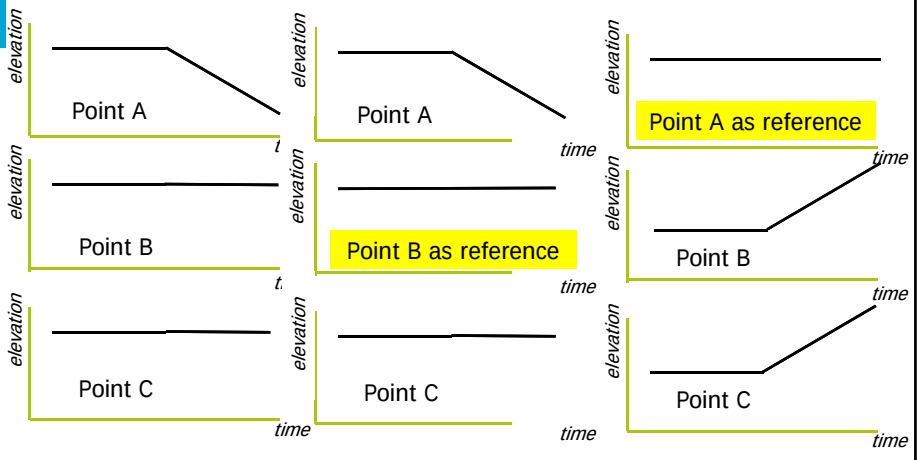


Can I interpret an InSAR time series? → Consequence

- InSAR time series are in **interval** scale, not **ratio** scale
- InSAR data are relative to a reference point and epoch

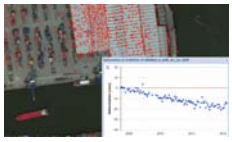
Time series bias





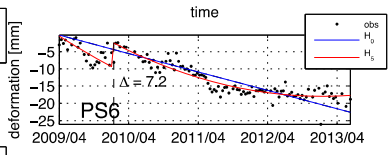
What is the precision of InSAR products?

- InSAR (total) precision composed of two parts:
  1. Measurement precision and data covariances
  2. Idealization precision



- Estimating InSAR total precision is **not** straightforward:
- 'coherence' requires an a priori model, i.e. a parameterization:

A '*Von Munchhausen*' problem

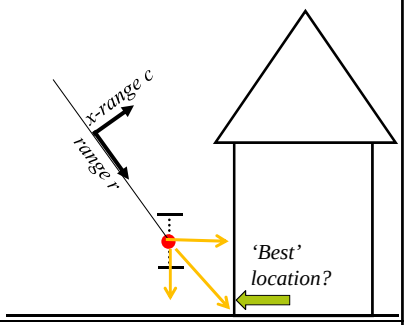


Which model describes the behaviour of my measurement (time-series) best?

Portal example: http://demo.portal.skygeo.com

What am I measuring?

- This is generally not known to sufficient detail
- Needs 3D positioning: range, azimuth, cross-range



Strengths, weaknesses, **OPPORTUNITIES**, threats

- Trivial: new satellites, technological/instrument developments,...
- Monitoring, monitoring, monitoring
- Making the deformation estimates absolute instead of relative
- Applying geodetic theory: model testing, Minimal Detectable Biases
- Extending to soft soils
- Quality assessment: including idealization precision
- 3D vector decomposition

Monitoring challenges

- Can we detect a hazardous building in Bangladesh, before it collapses?

- Can we identify a landslide before it becomes catastrophic?

- Can we get 'absolute' deformation measurements?
- Can we estimate subsidence over pastures?

- Can we predict a sinkhole before the collapse?

Strengths, weaknesses, **OPPORTUNITIES**, threats

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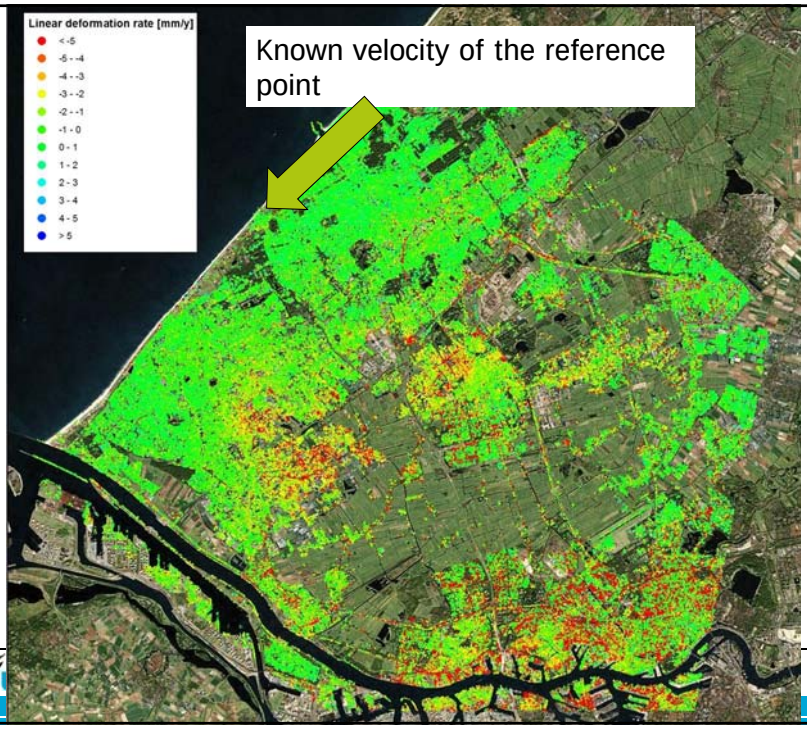
Geodetic datum connection - SARREF: Transponders at permanent GPS stations

SARREF concept

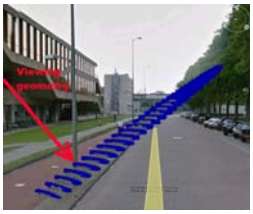
- Transponders mechanically connected to GPS stations

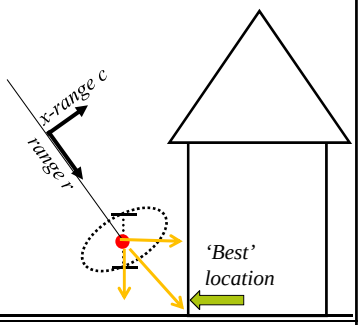
‘Absolute’ motion of large areas



InSAR positioning

- This is generally not known to sufficient detail
- Needs 3D positioning: range, azimuth, cross-range
- Cross-range only relative via interferometry, requires a GCP





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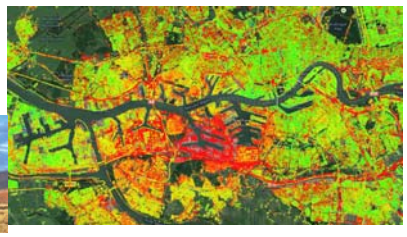
- 3D vector decomposition

The needle in the haystack



- **Primary:**

1. Find 'anomalous' points, e.g. potentially hazardous
2. Classify points according to temporal behavior

- **Secondary:**
- 3. Improve quality assessment of points

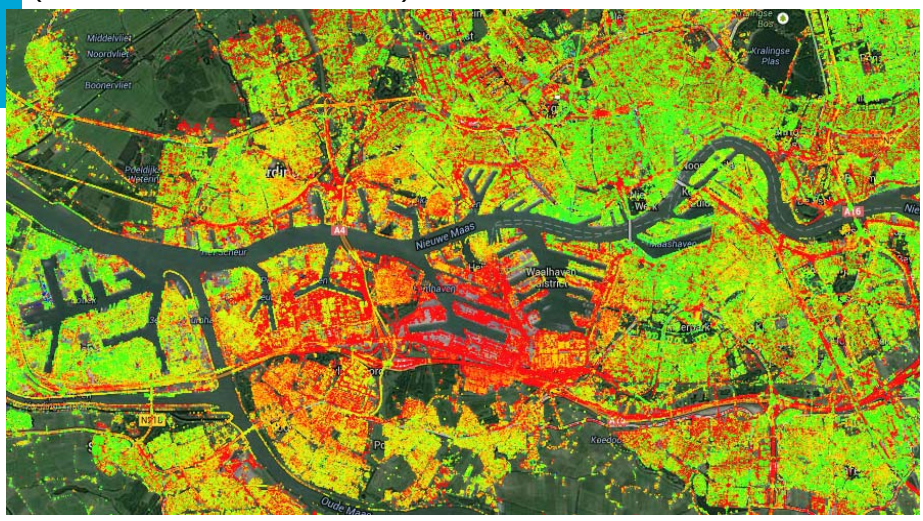
Model selection via hypothesis testing

- Many potential models (from library)
- Collect prior information from user (Interactive Query Tool)
- Select realistic optimal model as parameterization (Baarda's method)

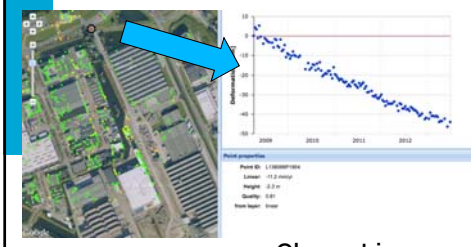
Methodology

- Based on testing different hypotheses for the temporal behavior
  - 'Steady-state' test: H_0: stability or linear motion
  - Using a 'library' of dynamic models: test alternative hypotheses
- Finding optimal solution via 'B-method of testing' and 'test ratios'

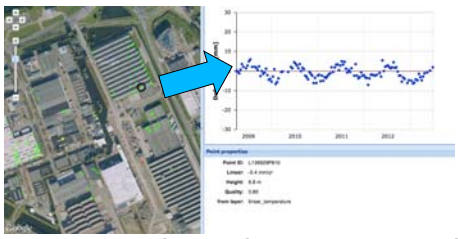
Real Terrasar-X data (m = 127) results:
(Rotterdam, the Netherlands)



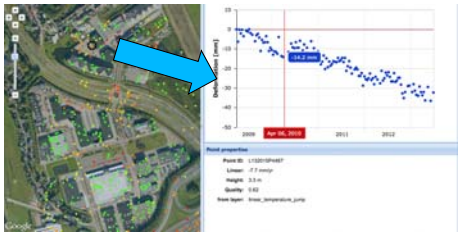
Real Terrasar-X data (m = 127) results: pointwise



Class: Linear



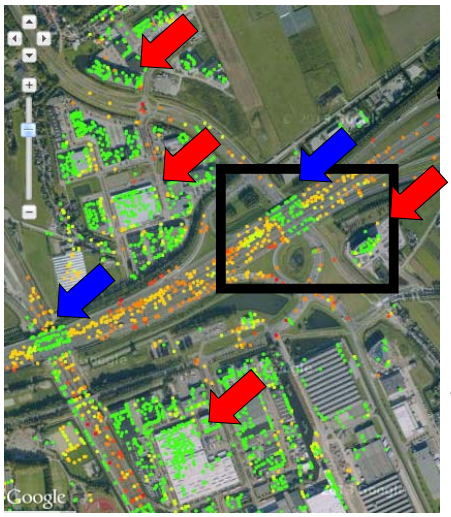
Class: Linear + seasonal



Class: Linear + seasonal + jump

Class: Linear + jump

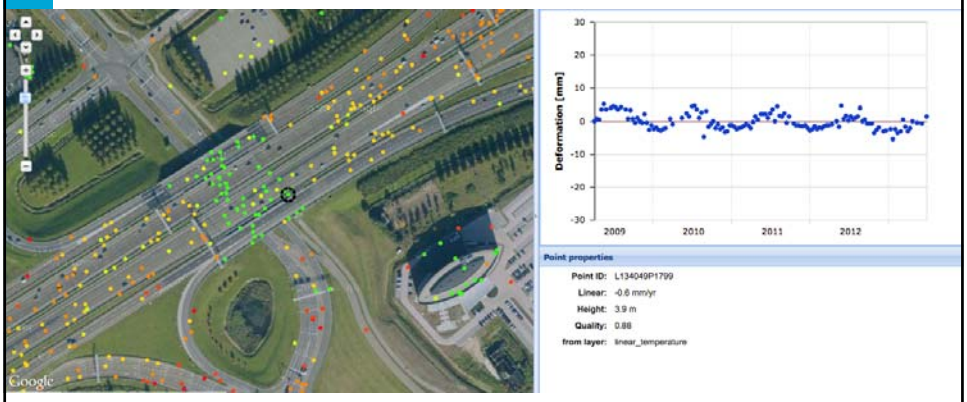
Real Terrasar-X data (m = 127) results: spatial distribution



Linear behavior:
e.g.
buildings,
bridges with good foundations

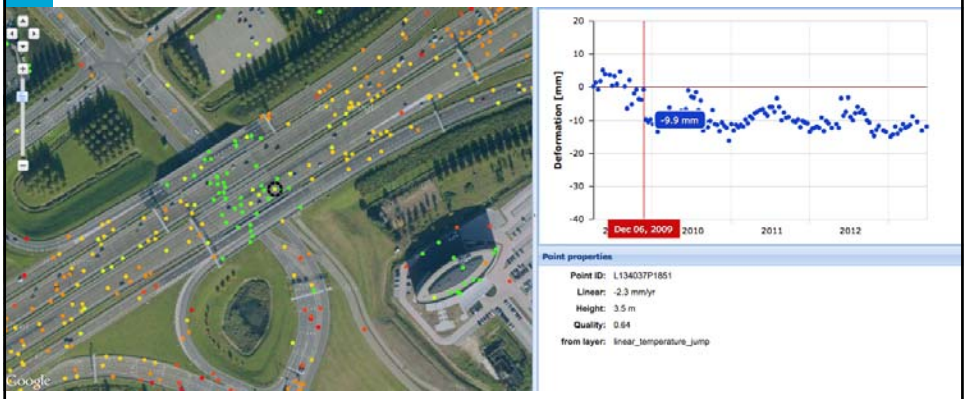
12 x 12 km

Real Terrasar-X data (m = 127) results: spatial distribution



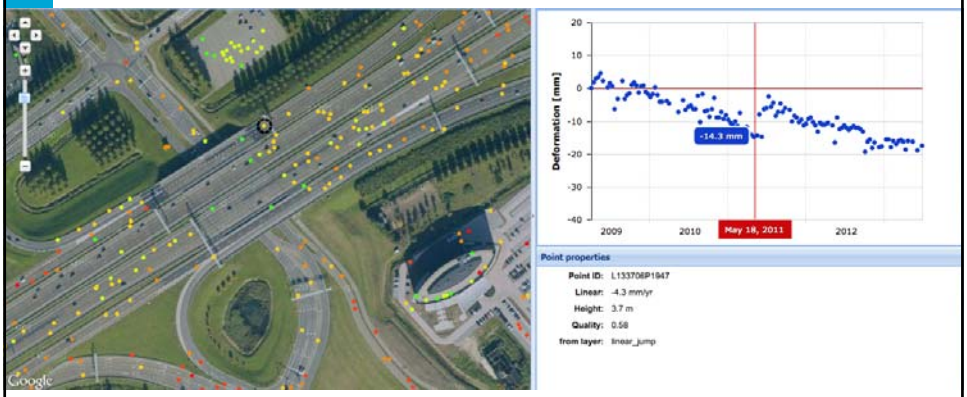
Model: linear + temperature

Real Terrasar-X data (m = 127) results: spatial distribution



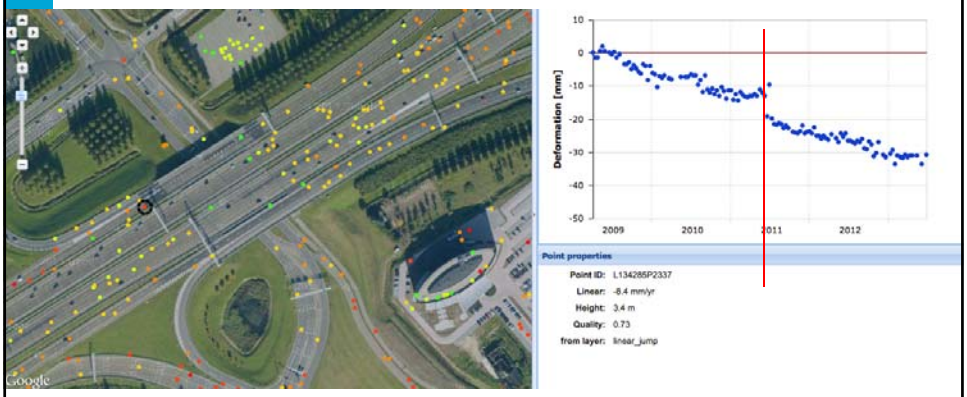
Model: linear + temperature + jump

Real Terrasar-X data (m = 127) results: spatial distribution



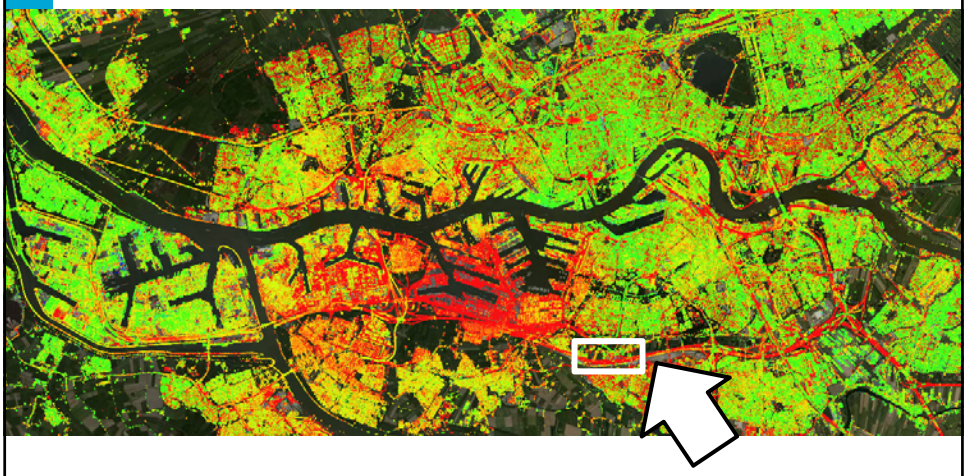
Model: linear + jump

Real Terrasar-X data (m = 127) results: spatial distribution



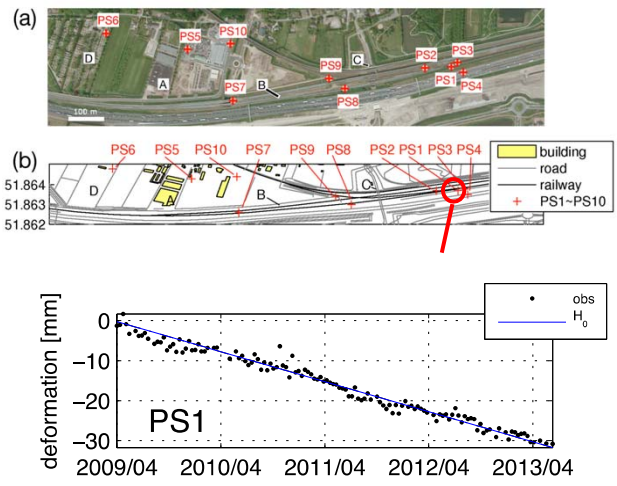
Model: linear + jump

Real Terrasar-X data (m = 127, 2009-2013) results: (Rotterdam, the Netherlands)



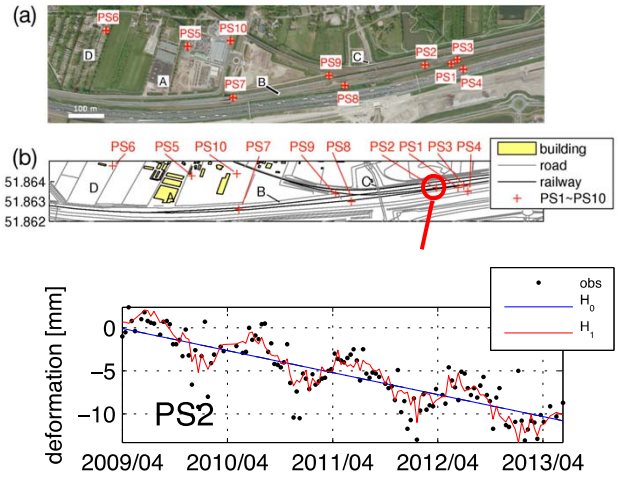
Web portal Skygeo

Real Terrasar-X data (m = 127) results: pointwise



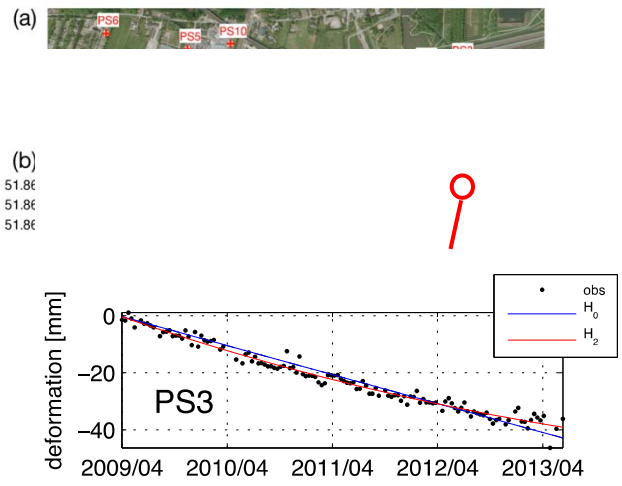
Class: Linear

Real Terrasar-X data (m = 127) results: pointwise



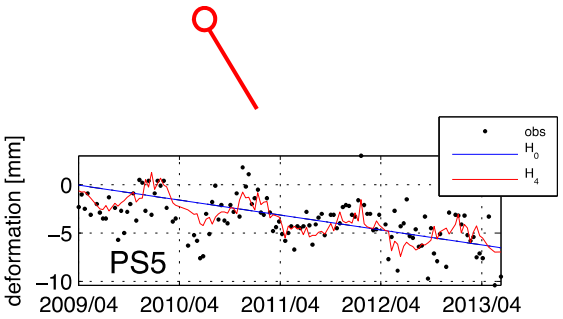
Class: Linear + temperature-related

Real Terrasar-X data (m = 127) results: pointwise



Class: Exponent

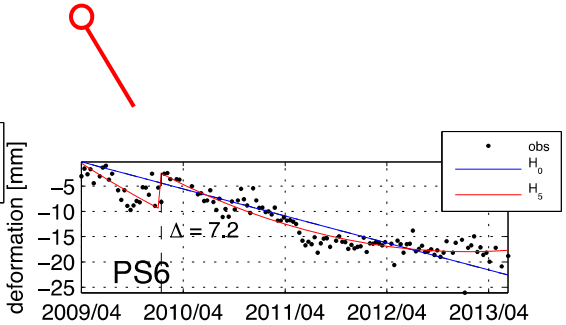
Real Ter



Class: Exponent + temperature-related

TUDelft

Strengths, Weaknesses, **Opportunities**, Threats



Class: Exponent + jump

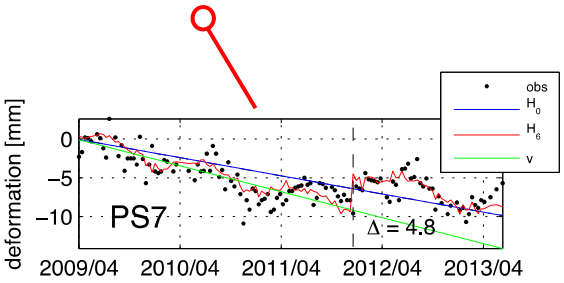
nge the future 79

Strengths, Weaknesses, **Opportunities**, Threats

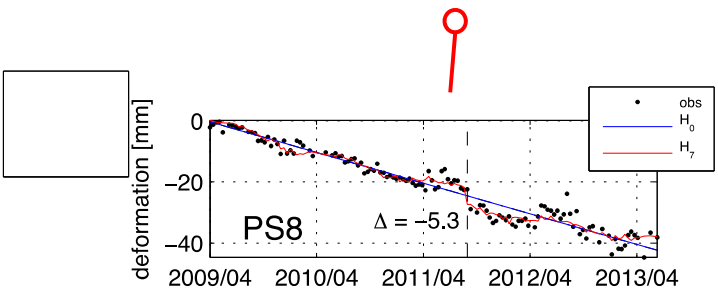
Real Ter

(a

(b



Class: Linear + temperature-related + jump



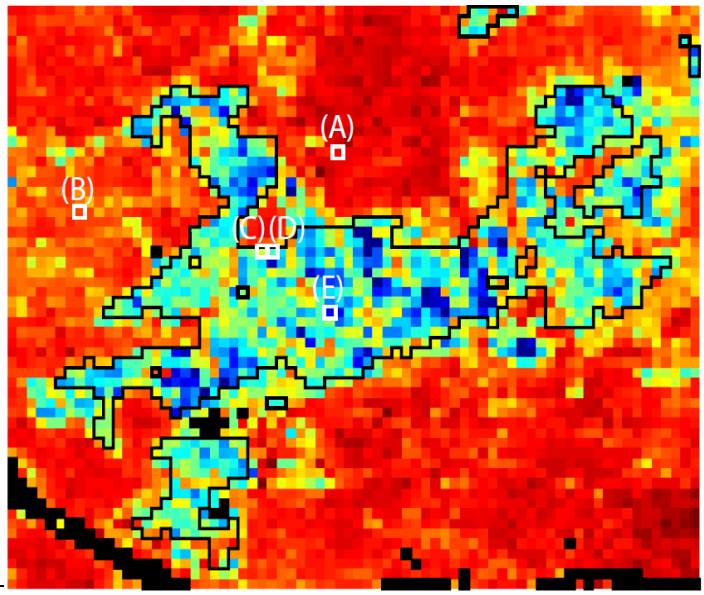
Class: Exponent + temperature-related + jump

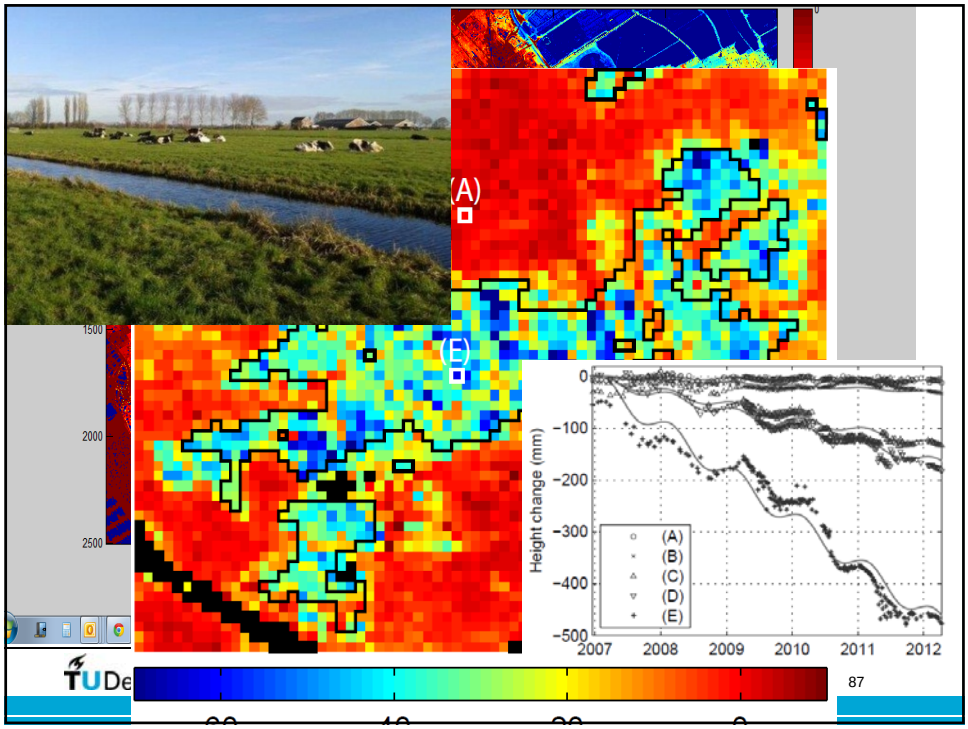
Strengths, weaknesses, **OPPORTUNITIES**, threats

- Trivial: new satellites, technological/instrument developments,...
- Monitoring, monitoring, monitoring
- Making the deformation estimates absolute instead of relative
- Applying geodetic theory: model testing, Minimal Detectable Biases
- Extending to soft soils
- Quality assessment: including idealization precision
- 3D vector decomposition

InSAR over pasture on peat

Peat oxidation and compaction



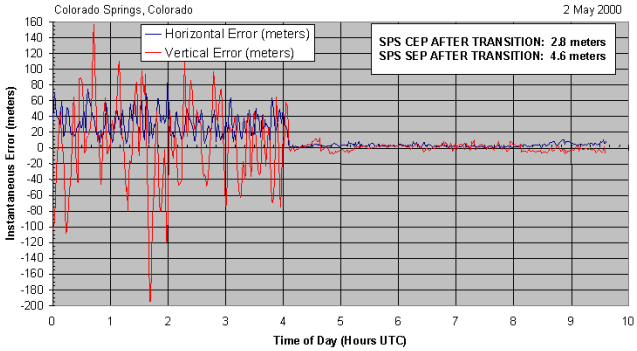


Strengths, weaknesses, opportunities, **THREATS**

- Accessibility, accessibility, accessibility
  (data policies, business models, pricing)
- Mission (service) discontinuation
- "One-size fits all" trade-offs lead to ineffective compromise
- Overselling, Quality claims cannot be supported, idealization precision

Clinton's decision to discontinue Selective Availability

SA Transition -- 2 May 2000



Netherlands Space Office

Ministerie van Economische Zaken, Landbouw en Innovatie

ALTERRA WAGENINGEN UR

Establishment Dutch National Satellite Dataportal in preparation to SENTINELS

Mücher, C.A., van Loon, J.P., Roerink, G.J., van Benthem, J.M.H., Lips, F.

Satellite portal

The data portal (http://www.spaceoffice.nl/nl/Satellietdataportaal/) will not provide ready-made products. It will provide the (free) access to raw satellite data from the Netherlands. In general, radiometric correction is planned, but no ortho-rectification. The Satellite Data Portal provides access to raw satellite data of the Netherlands from various satellite sensors. Both optical and radar satellite imagery will be available at a range of spectral, spatial and temporal resolutions. Below is an overview of the current range of satellite data in the Satellite Data Portal. During the project (2012-2015) the data portal will be extended with new instruments based on discussions with the Dutch research and user community.

Satellite	Data	Bands/polarisatio*	Spatial Resolution	Temporal Resolution
Formosat-2	Panchromatic	Blue-NIR (1 band)	2 meter**	Every 9 days
Formosat-2	Multispectral	Blue, Green, Red, NIR	8 meter	Every 9 days
UK-DMC-2	Multispectral	Green, Red, NIR	22 meter	3 times a week
Deimos-1	Multispectral	Green, Red, NIR	22 meter	3 times a week
Radarsat-2	Radar	HH+HV polarisation	25 meter	Every 24 days
Radarsat-2	Radar	VV+VH polarisation	25 meter	Every 24 days

Strengths, weaknesses, opportunities, **THREATS**

- Accessibility, accessibility, accessibility
  (data policies, business models, pricing)
- Mission (service) discontinuation
- "One-size fits all" trade-offs lead to ineffective compromise
- Overselling, Quality claims cannot be supported, idealization precision

Conclusions: "an InSAR SWOT"

- Strengths: *data availability, precision, technology readiness level, end users (science, commercial)*
- Weaknesses: *opportunistic, reliability, resolution needs, QA/QC*
- Opportunities: *entering the golden age of InSAR: monitoring. Involve more disciplines*
- Threats: *reliability and interpretability are show-stoppers! Data availability and continuity*