Surface deformation of the whole Netherlands after PSI analysis

Miguel Caro Cuenca, Ramon Hanssen, Andy Hooper and Mahmut Arikan

Background and motivation

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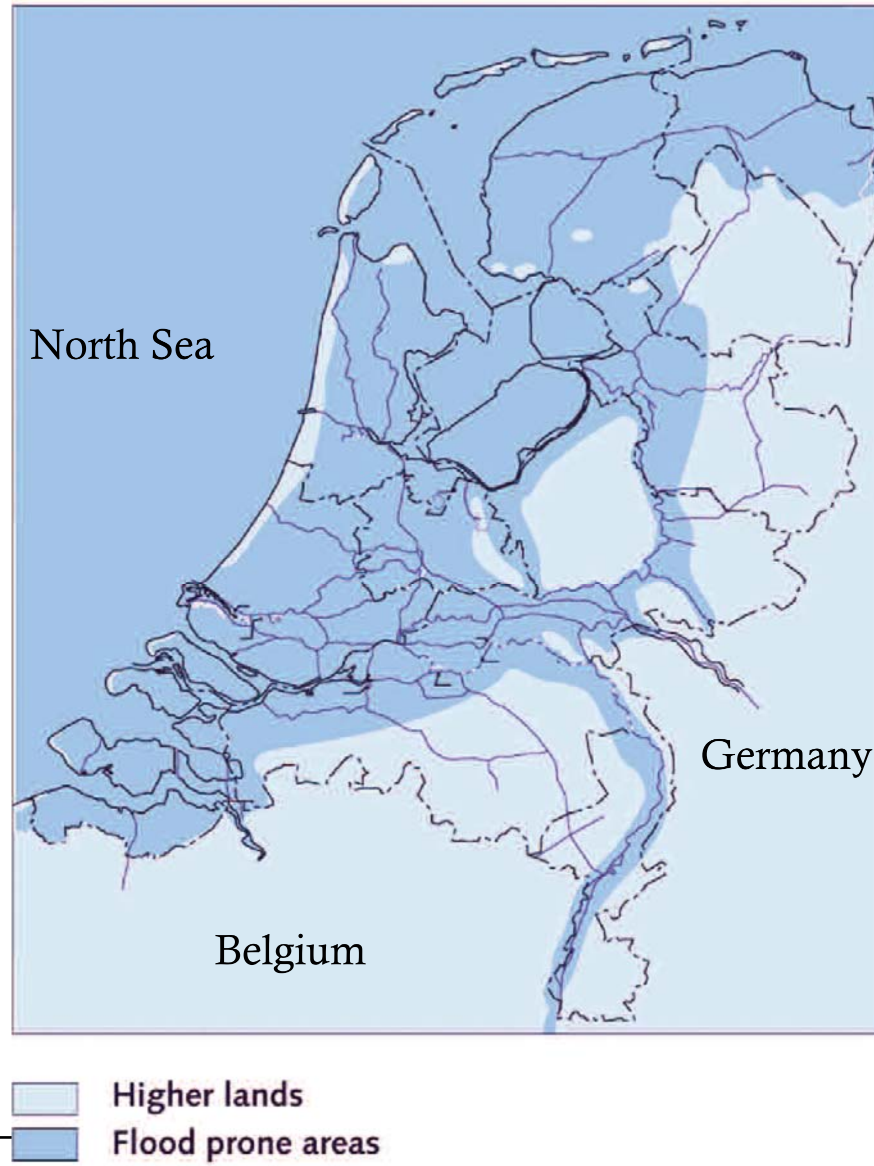


Rijkswaterstaat, 2006, “Flood maps in the Netherlands”

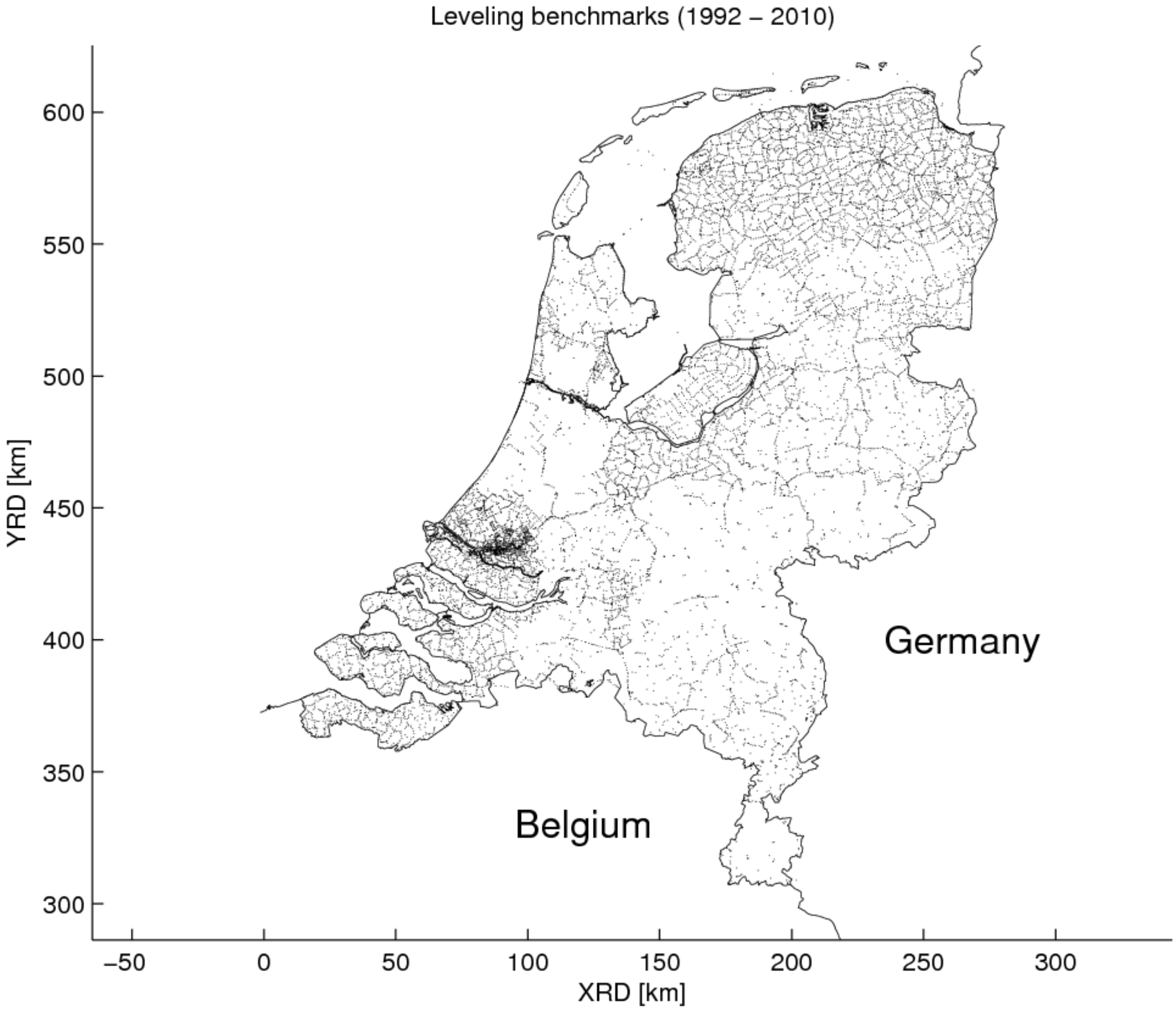
Main objective

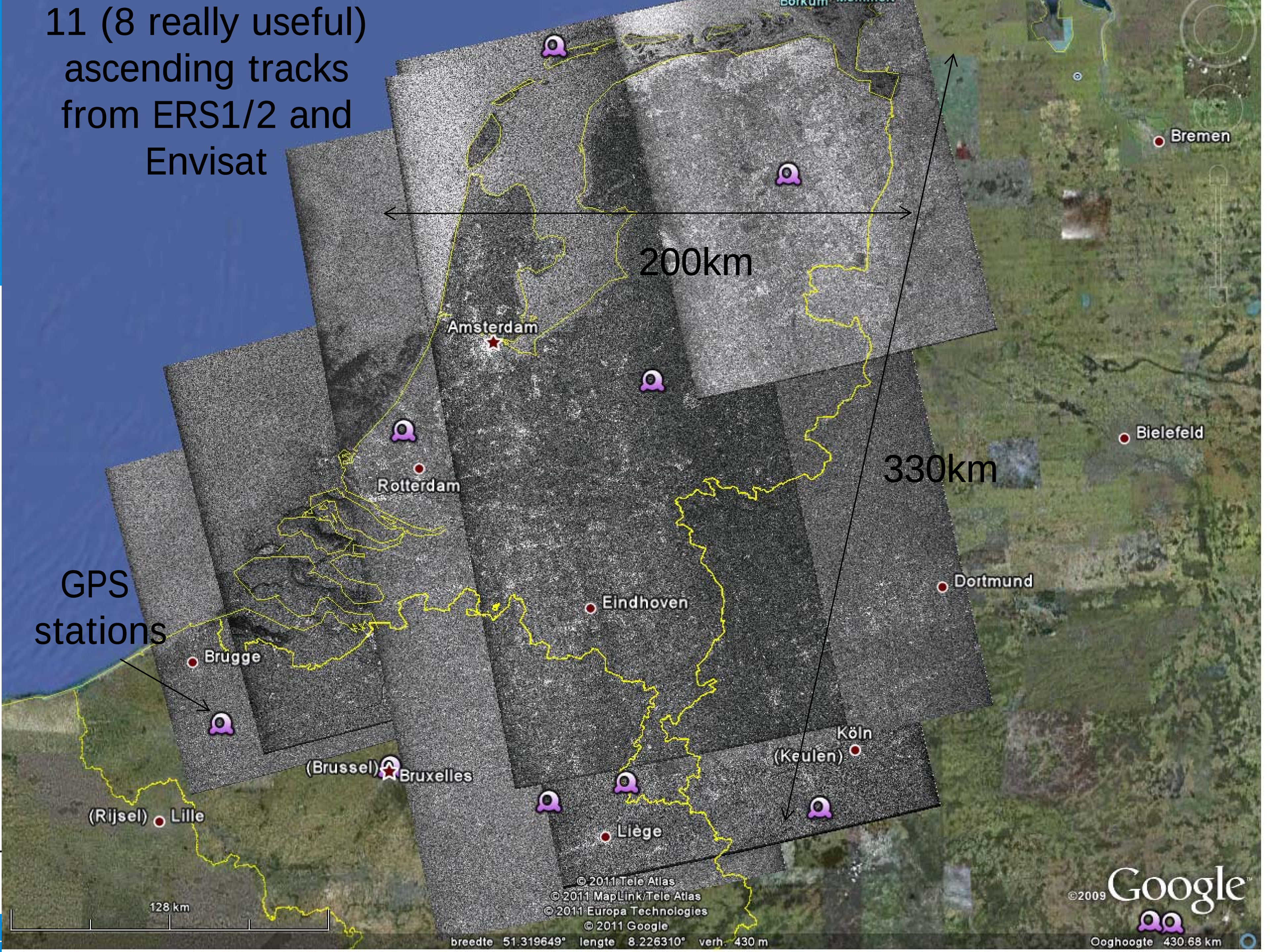
To create a deformation (rates) map of the whole the Netherlands using all available data.

Available data

- **GPS**: 9 continuous GPS stations starting in late 1990's. Provided by EUREF network.
- **Leveling**: 17.000 benchmarks and average measurement period of ~5 yrs. Time span 1992-2010 but area dependent. Provided by the Dutch ministry of transport.
- **InSAR**: Millions of observations and a repeating period of ~35 days with data gaps. Time span 1992-2010. Provided by ESA.

Leveling network (1992-2010)




11 (8 really useful) ascending tracks from ERS1/2 and Envisat
200km
330km
GPS stations
Amsterdam
Rotterdam
Eindhoven
Brugge
(Brussel) Bruxelles
(Rijsel) Lille
Liège
Köln
(Keulen)
Dortmund
Bielefeld
Bremen
128 km
© 2011 Tele Atlas
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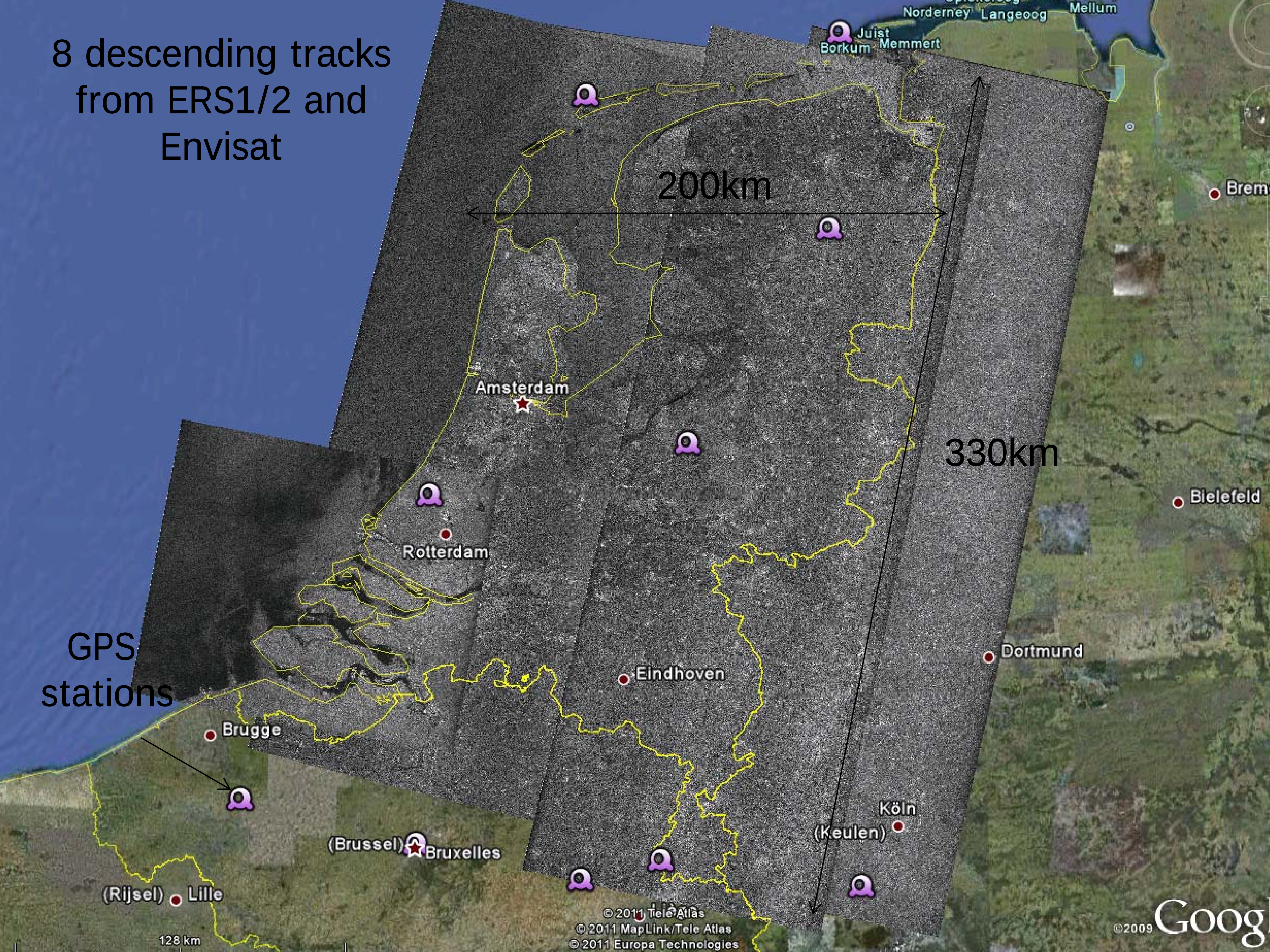
©2009 Google
breedte 51.319649° lengte 8.226310° verh. 430 m
Ooghoogte 430.68 km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Lille
128 km
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Data processing: GPS

- Estimated rates and standard deviation provided by EUREF

Data processing: Leveling

- Time series provided by Rijkswaterstaat (Dutch ministry of transport)
- We corrected time series to old Dutch datum (NAP)

and estimated linear rates using least squares. Outlier rejection tests.

Data processing: InSAR

- RAW images provided by ESA with customized length
- Focused with ROI-PAC
- InSAR processing with Doris
- Time series analysis with Stamps

Time series analysis

• For tracks with number of images > 30: Persistent Scatterer approach.

• For tracks with number of images <= 30 or potentially complex phase unwrapping : Multi-Temporal InSAR (**MTI**) (Combination of Small Baseline and Persistent Scatterer approaches , A. Hooper, (2008)).

- Once the interferograms are unwrapped, orbit ramps and atmosphere are estimated and removed. Remaining orbit errors are removed in a later stage.

- We then calculate linear rates per coherent pixel.

Data combination

- Estimated rates must be referenced with respect to the same reference frame.

- We select leveling reference system (the Dutch Datum known as NAP)

Data combination

- We interpolate (no extrapolation) all available data to a common 500 x 500 m^2 grid with ordinary kriging.
- We estimate the variance for each interpolated value with kriging.

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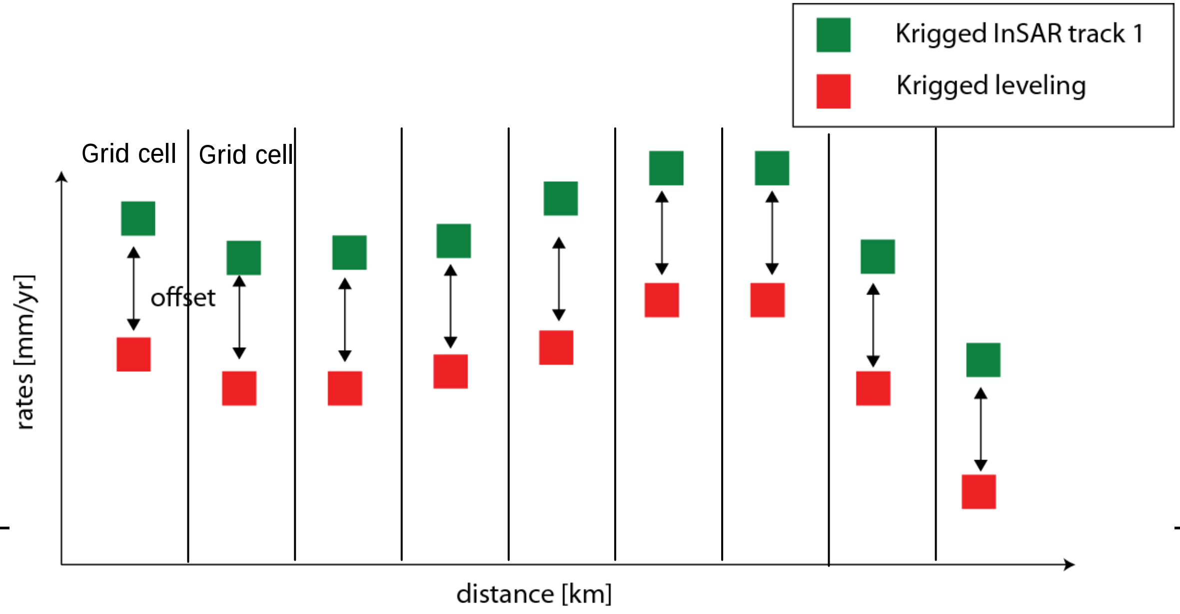

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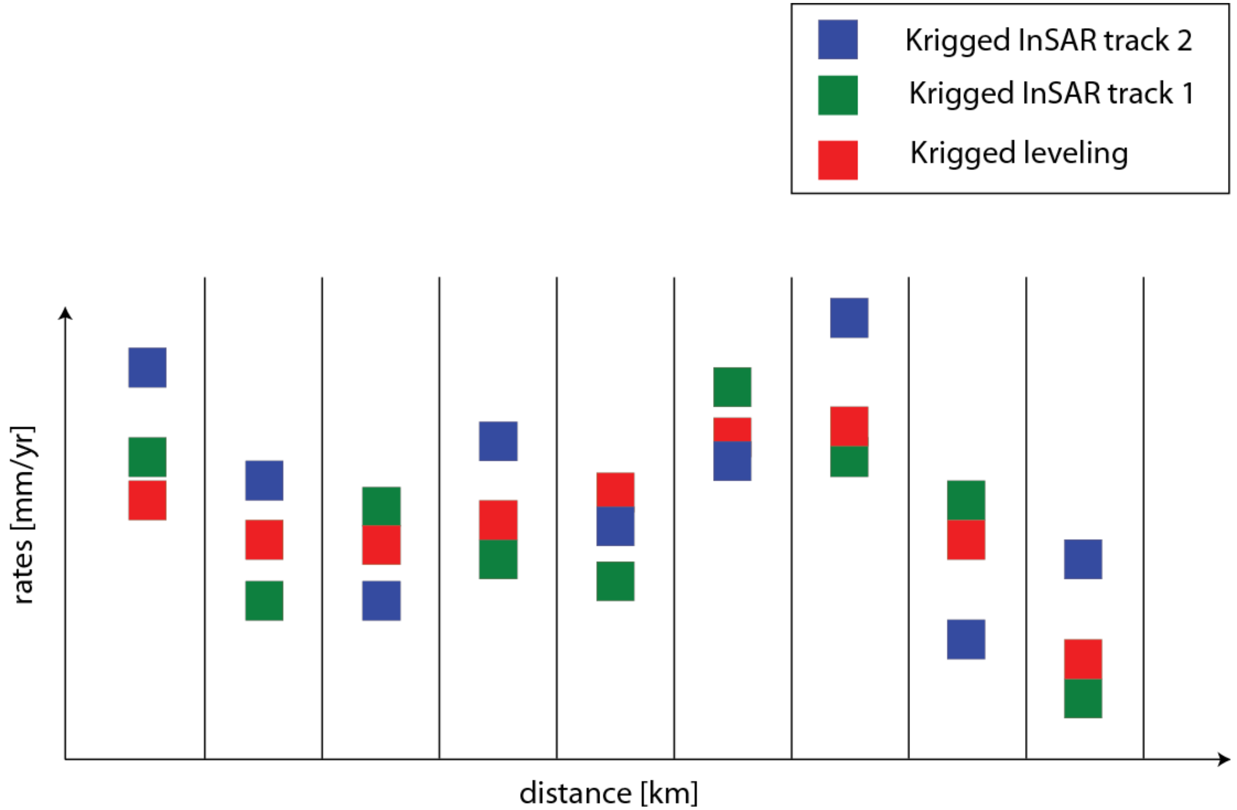
$$E\left\{\begin{bmatrix} v^1_{\text{ers,desc}} - v^1_{\text{lev(LOS)}} \\ \vdots \\ v^n_{\text{ers,desc}} - v^n_{\text{lev(LOS)}} \end{bmatrix}\right\} = \begin{bmatrix} 1 \\ \vdots \\ 1 \end{bmatrix} \begin{bmatrix} x_{\text{offset}} \end{bmatrix}, \quad D\left\{\begin{bmatrix} v^1_{\text{ers,desc}} - v^1_{\text{lev(LOS))}} \\ \vdots \\ v^n_{\text{ers,desc}} - v^n_{\text{lev(LOS)}} \end{bmatrix}\right\} = \begin{bmatrix} \sigma^{2,1}_{\text{ers,desc}} + \sigma^{2,1}_{\text{lev(LOS)}} & 0 & \dots & 0 \\ \vdots & & & \\ 0 & \dots & 0 & \sigma^{2,n}_{\text{ers,desc}} + \sigma^{2,n}_{\text{lev(LOS)}} \end{bmatrix}$$

Data combination

- We assume that leveling, GPS, ERS1/2 and Envisat observe the same signal. We realize it is a strong assumption i.e. the results contain average linear rates.



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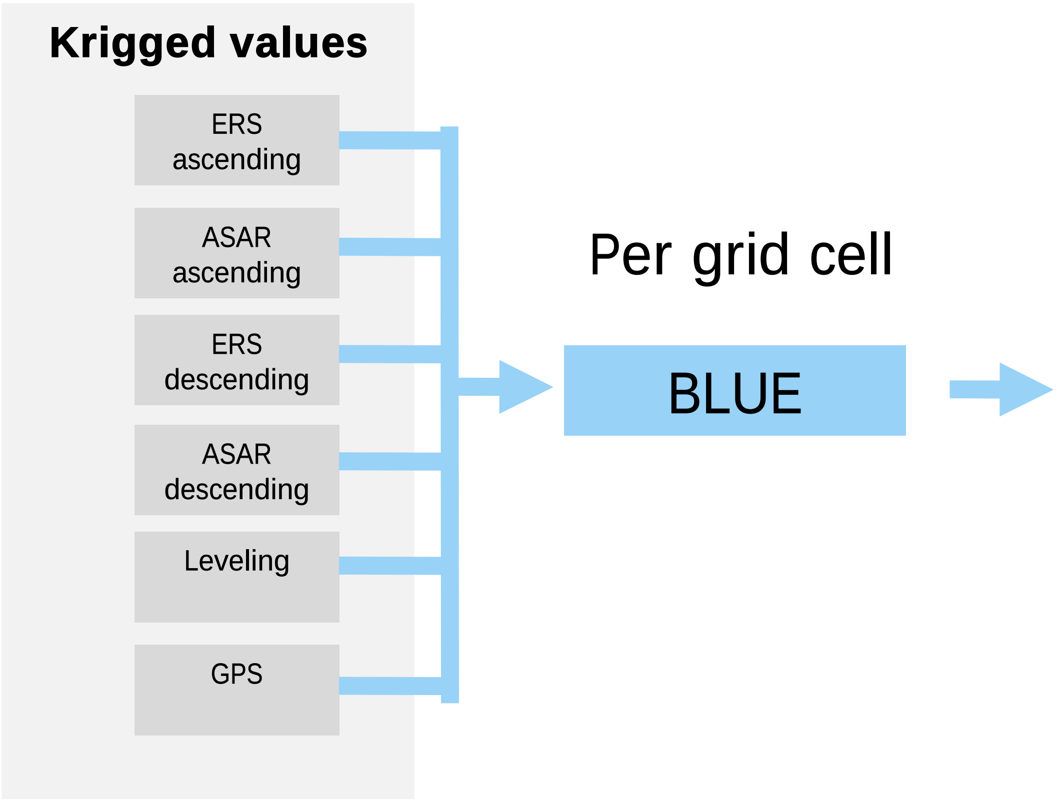

$$\begin{bmatrix} \hat{V} \\ \hat{H}_{East} \end{bmatrix}$$

Data combination

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- Per grid cell, the functional and stochastic models are:

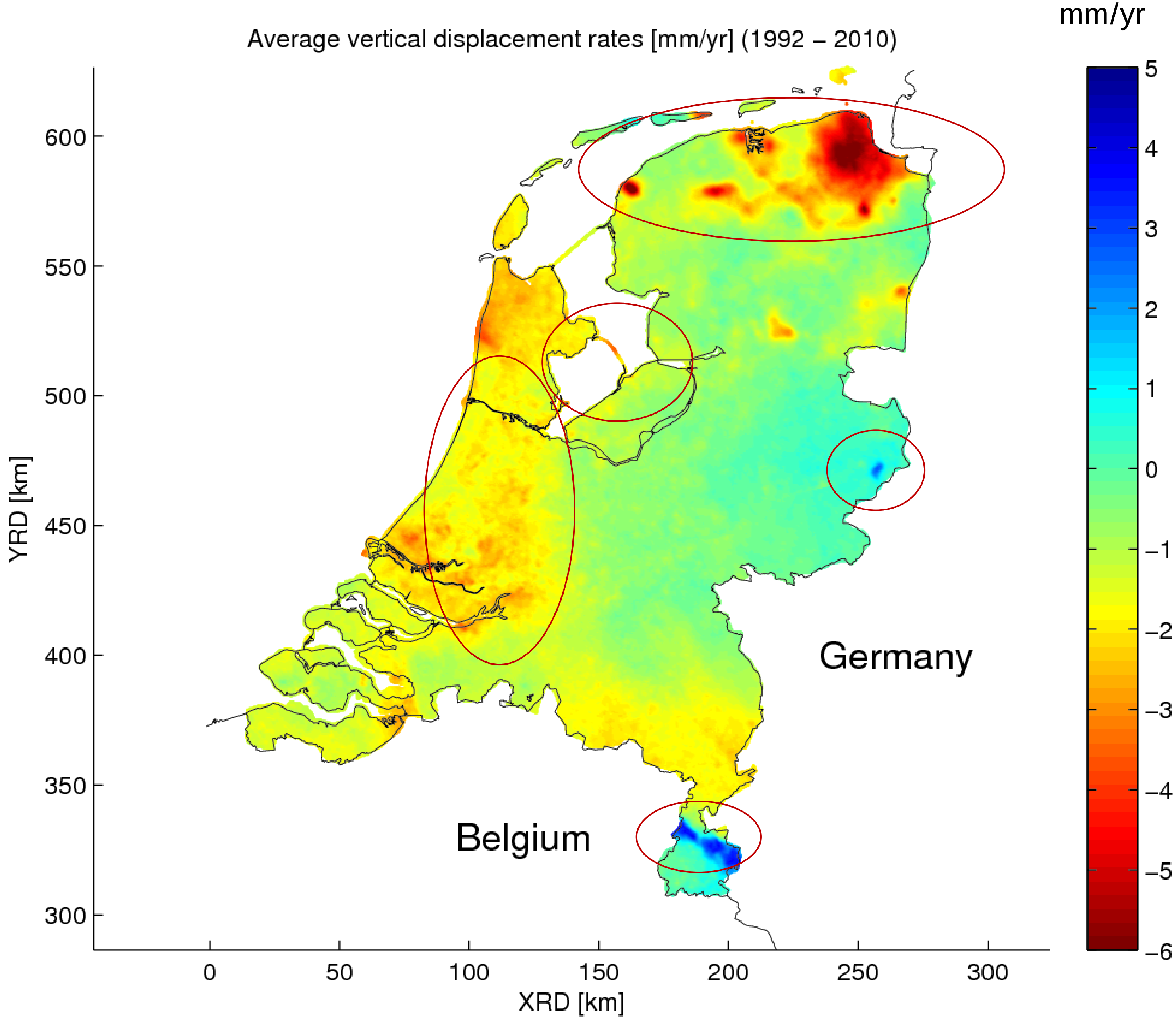
$$E\{\begin{bmatrix} v_{\text{ers,asc}} \\ v_{\text{asar,asc}} \\ v_{\text{ers,desc}} \\ v_{\text{asar,desc}} \\ v_{\text{lev}} \end{bmatrix}\} = \begin{bmatrix} \cos\theta & -\sin\theta\cos\alpha_{\text{asc}} \\ \cos\theta & -\sin\theta\cos\alpha_{\text{asc}} \\ \cos\theta & \sin\theta\cos\alpha_{\text{desc}} \\ \cos\theta & \sin\theta\cos\alpha_{\text{desc}} \\ 1 & 0 \end{bmatrix} \begin{bmatrix} V \\ H_{East} \end{bmatrix}, \quad D\{\begin{bmatrix} v_{\text{ers,asc}} \\ v_{\text{asar,asc}} \\ v_{\text{ers,desc}} \\ v_{\text{asar,desc}} \\ v_{\text{lev}} \end{bmatrix}\} = \begin{bmatrix} \sigma^2_{\text{ers,asc}} & 0 & 0 & 0 & 0 \\ 0 & \sigma^2_{\text{asar,asc}} & 0 & 0 & 0 \\ 0 & 0 & \sigma^2_{\text{ers,desc}} & 0 & 0 \\ 0 & 0 & 0 & \sigma^2_{\text{asar,desc}} & 0 \\ 0 & 0 & 0 & 0 & \sigma^2_{\text{lev}} \end{bmatrix}$$

- InSAR residual contains unmodeled atmosphere and unmodeled orbit errors

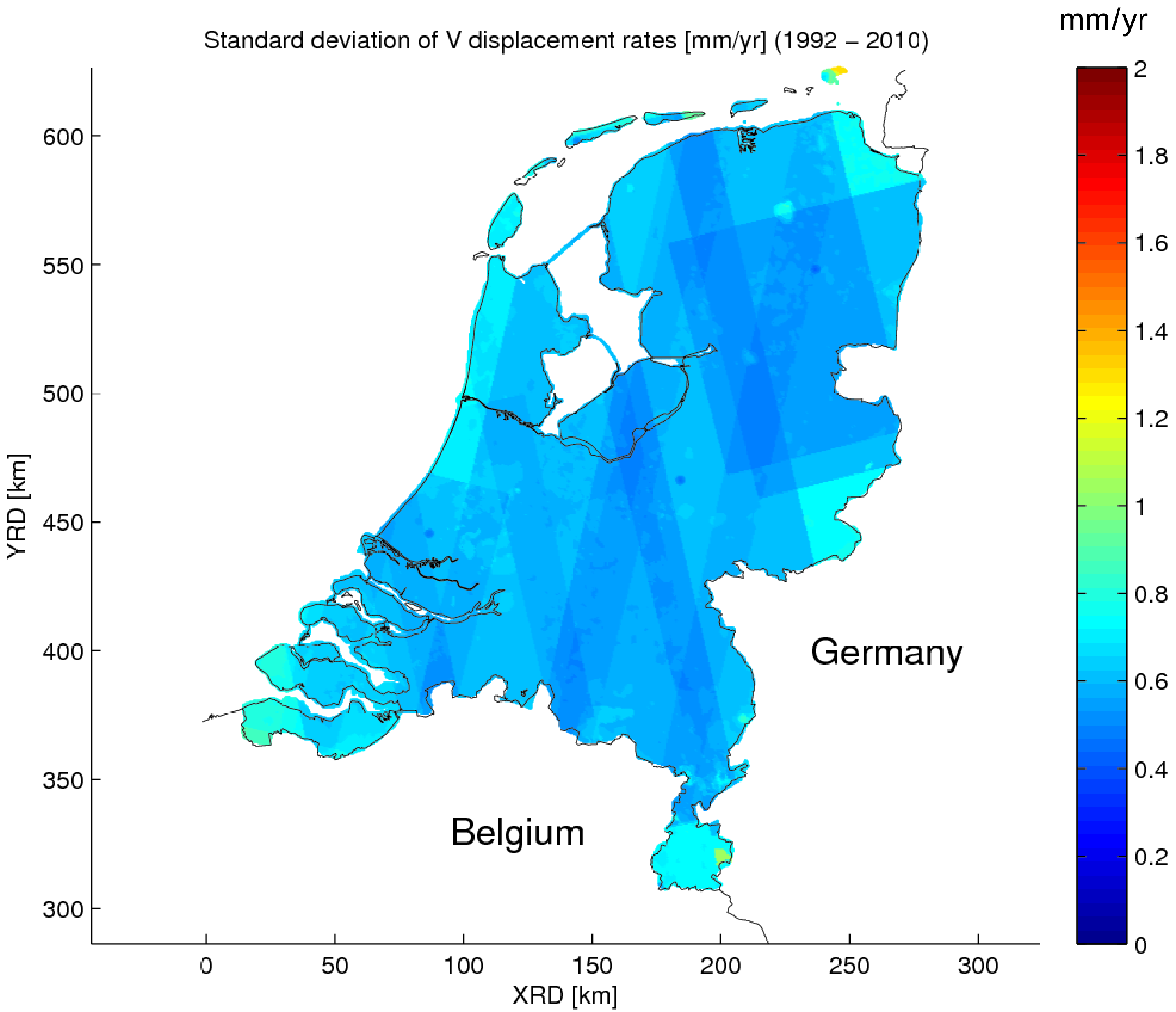
- We low pass filter the InSAR residuals (20km window) to obtain the remaining atmosphere and orbit errors and remove them from InSAR observations.

Results

Vertical rates

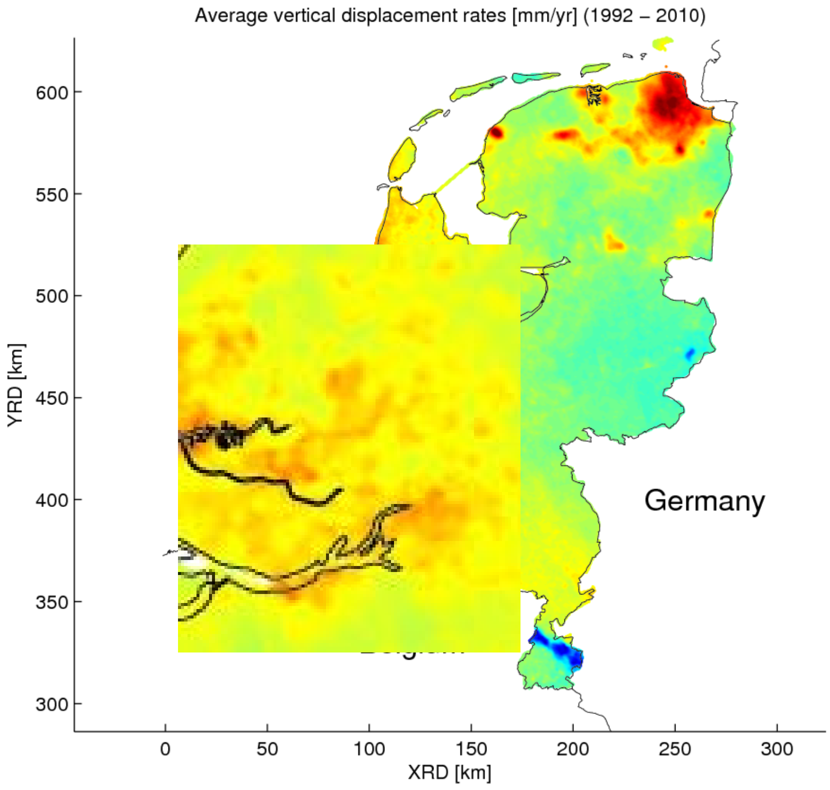


Precision vertical rates

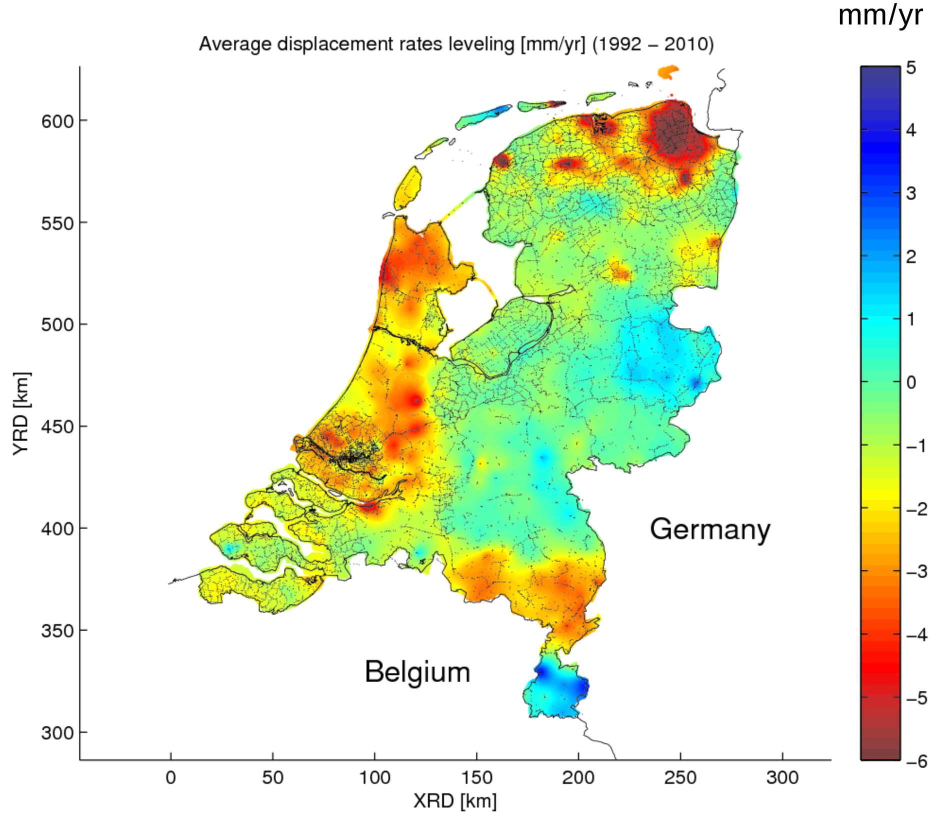


(Only) InSAR vs. leveling

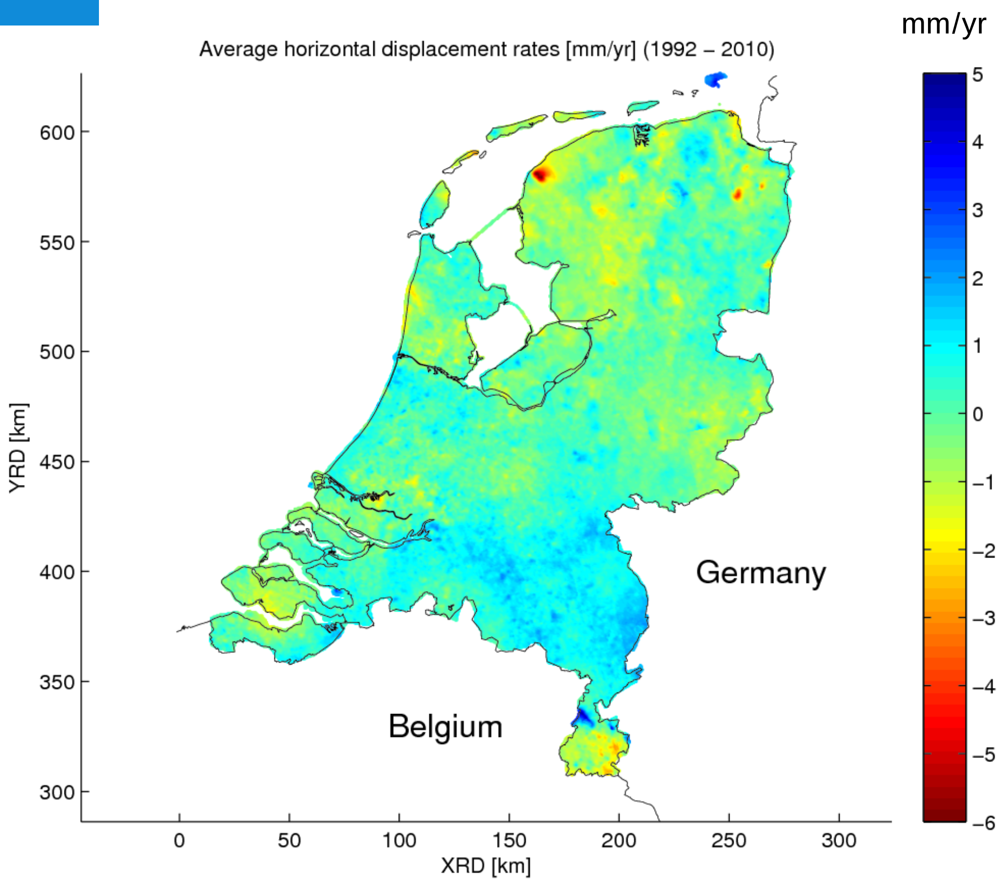
InSAR

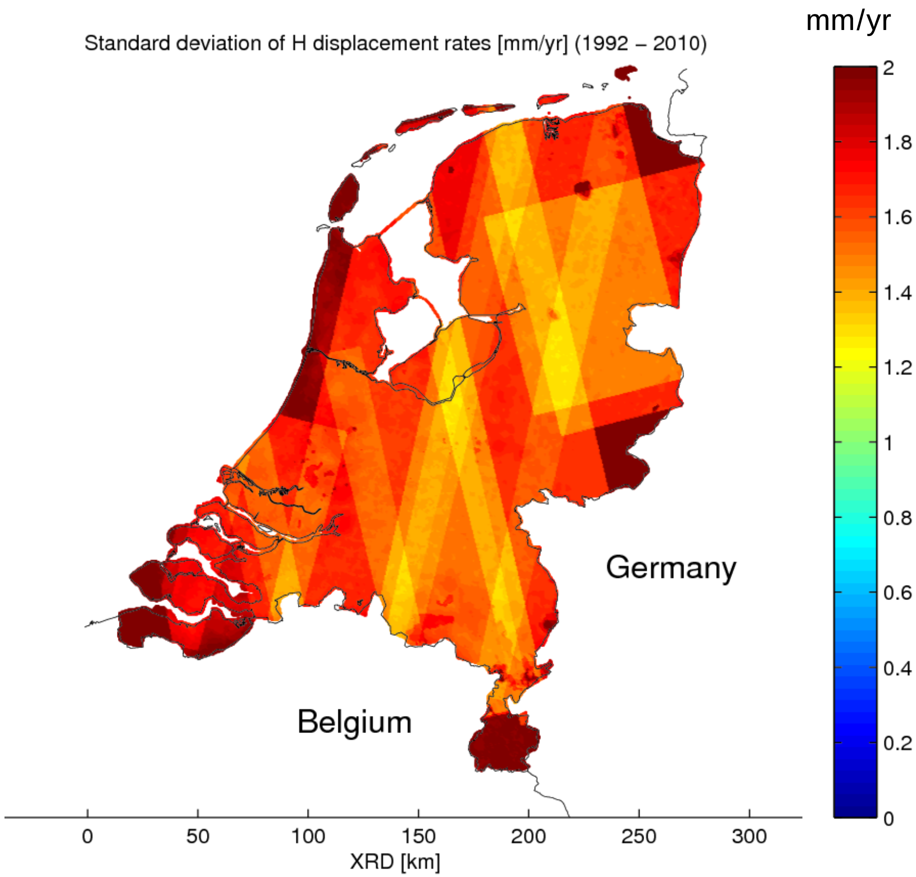


Leveling

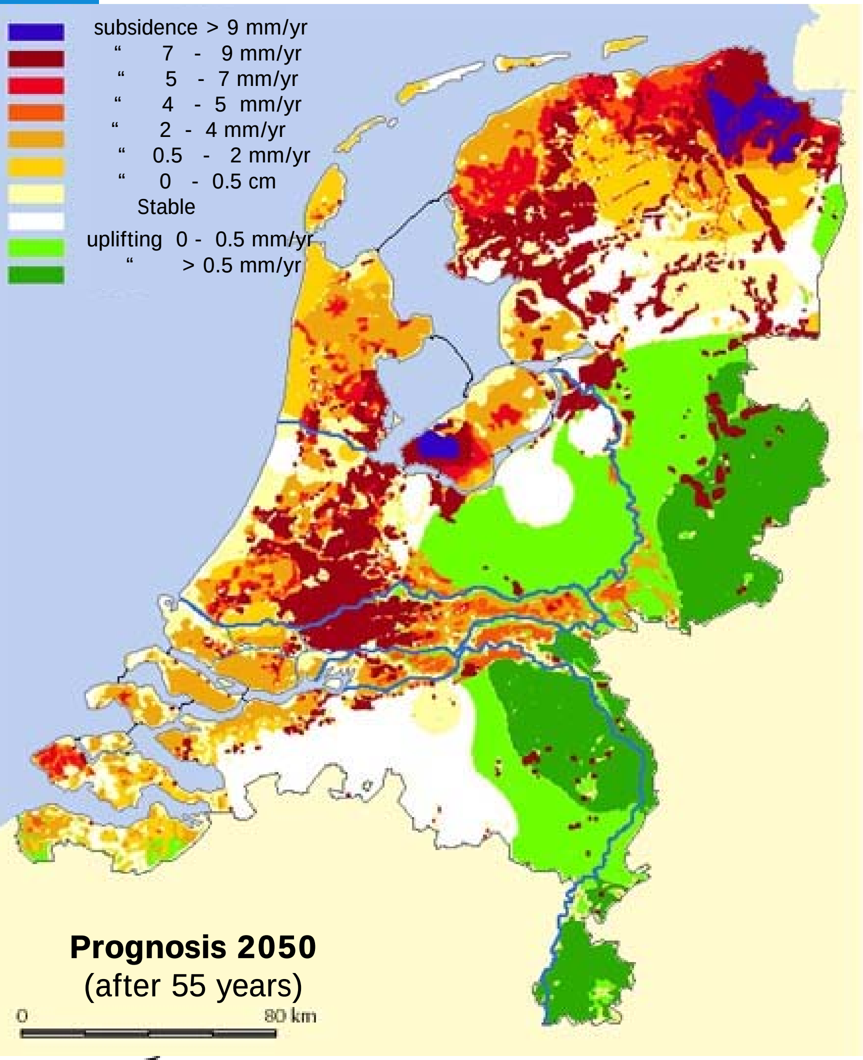


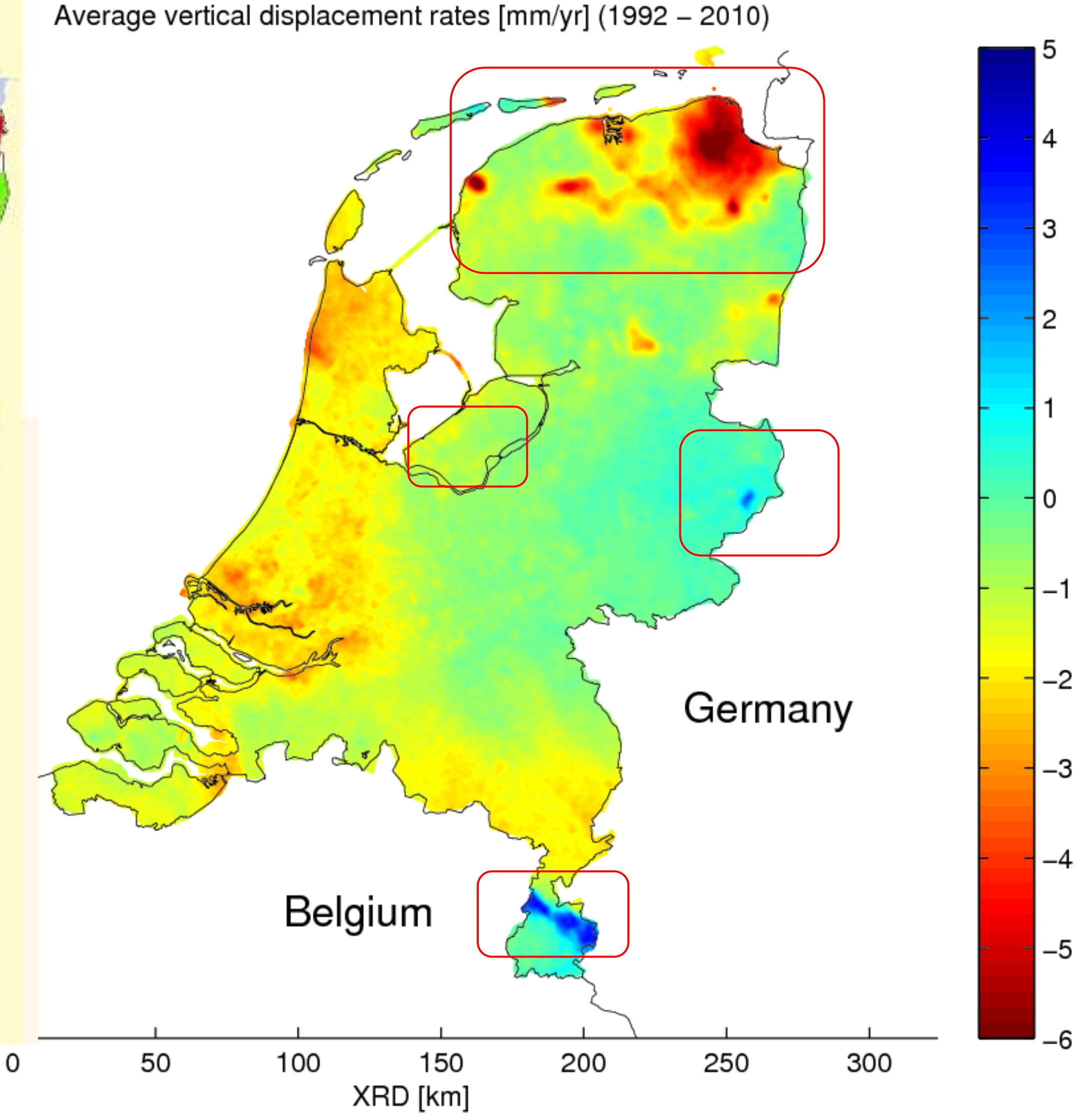
Horizontal (E-W) rates and precision





Comparison with previous studies





Summary and Conclusions

- We have processed all available data over the Netherlands including leveling, InSAR and GPS.
- We have produced a map of the average displacement rates in the Netherlands covering the last ~18 years.
- The map provides with an overview of the processes affecting the Netherlands, such as, sediment compaction, gas production, water rebound and glacial isostatic adjustment.
- We have estimated the variance of the rates but it seems underestimated. More effort should be place in the stochastic model.

Future work

- Analysis of temporal behavior.

- Improvement of the stochastic model.

- Analysis of results focusing on distinguishing between shallow (e.g. sediment compaction) and deep (e.g., gas production) processes.