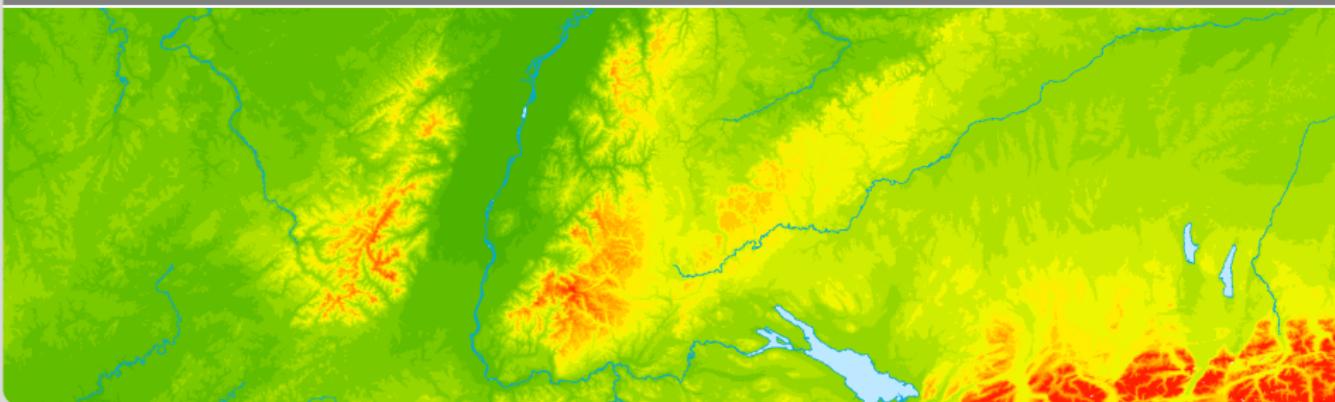


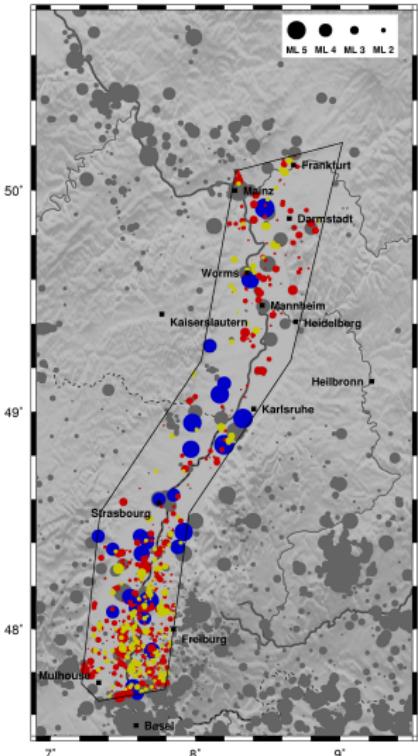
Recent Surface Displacements in the Upper Rhine Graben Area Derived from Precise Levelling and SAR Interferometry

Thomas Fuhrmann, Andreas Schenk, Malte Westerhaus, Karl Zippelt, Bernhard Heck

GEODETIC INSTITUTE, PHYSICAL AND SATELLITE GEODESY

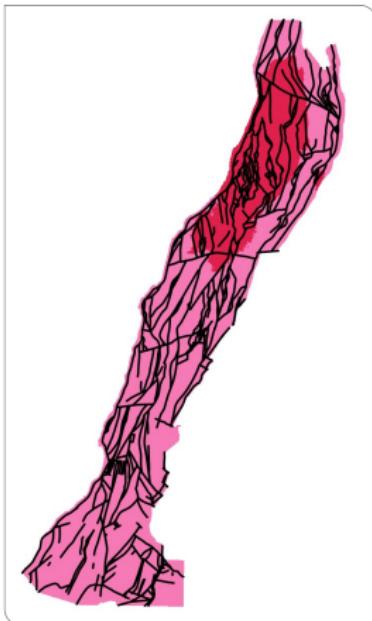


Motivation - Upper Rhine Graben (URG)



Seismicity in the URG (Barth & Ritter, JLG, 2009)

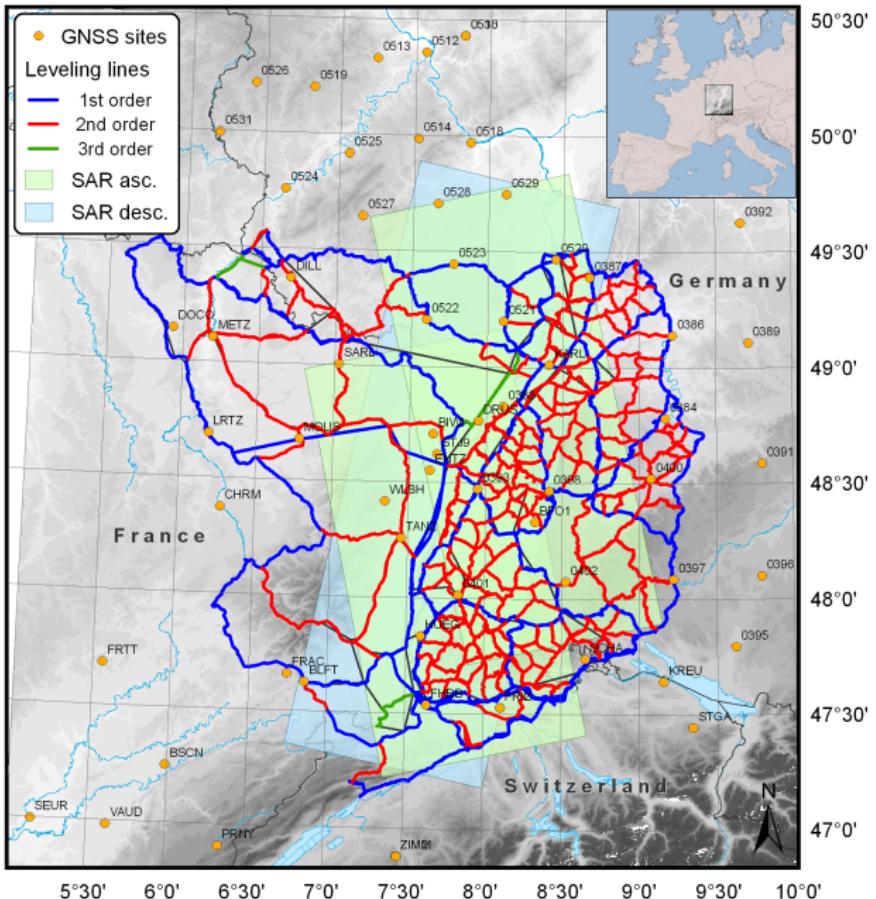
- active tectonics
- anthropogenic use

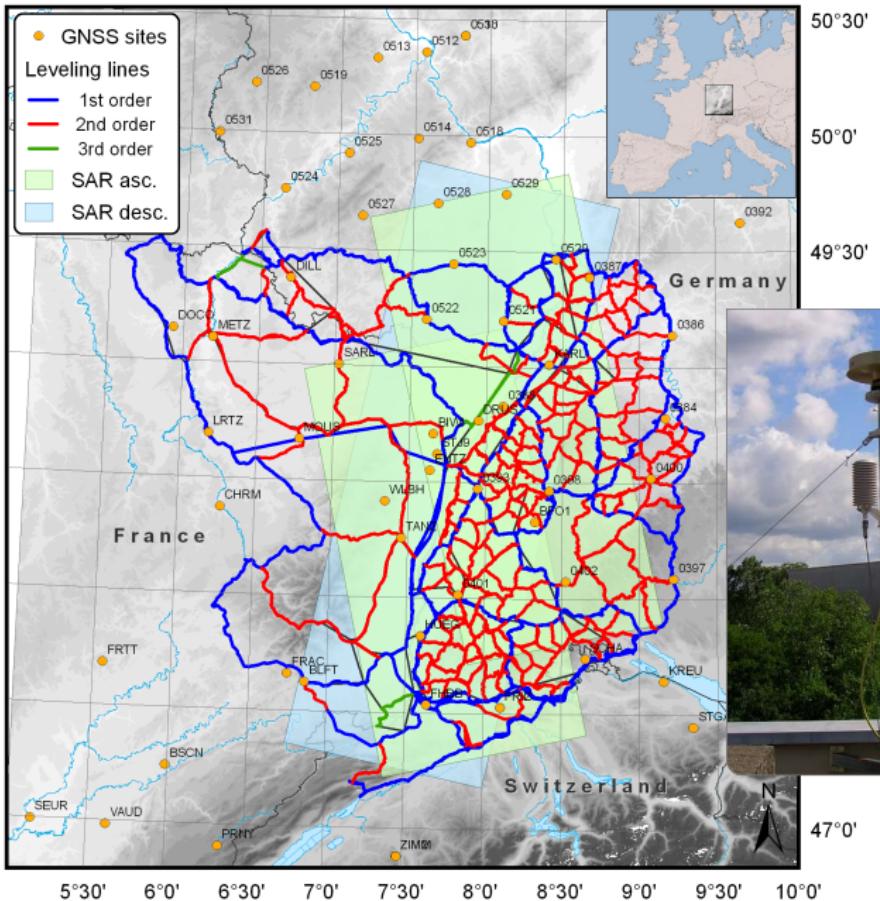


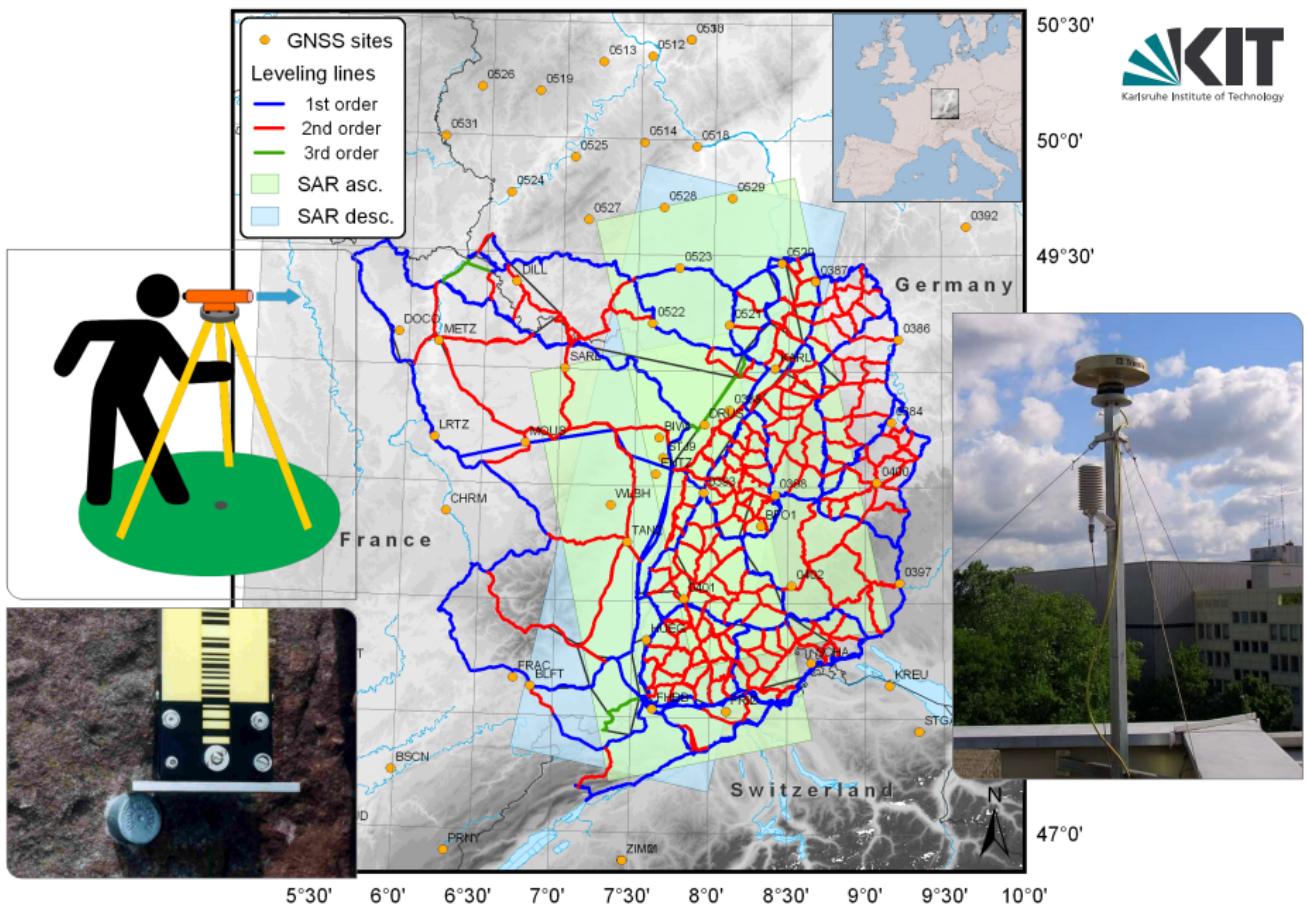
Temperatures required for geothermal use in 3000 m below surface

- > 150 °C: very high potential for power generation
- 100-150 °C: power generation
- 60-100 °C: direct usage of thermal heat
- < 60 °C: balneologic use and heat supply

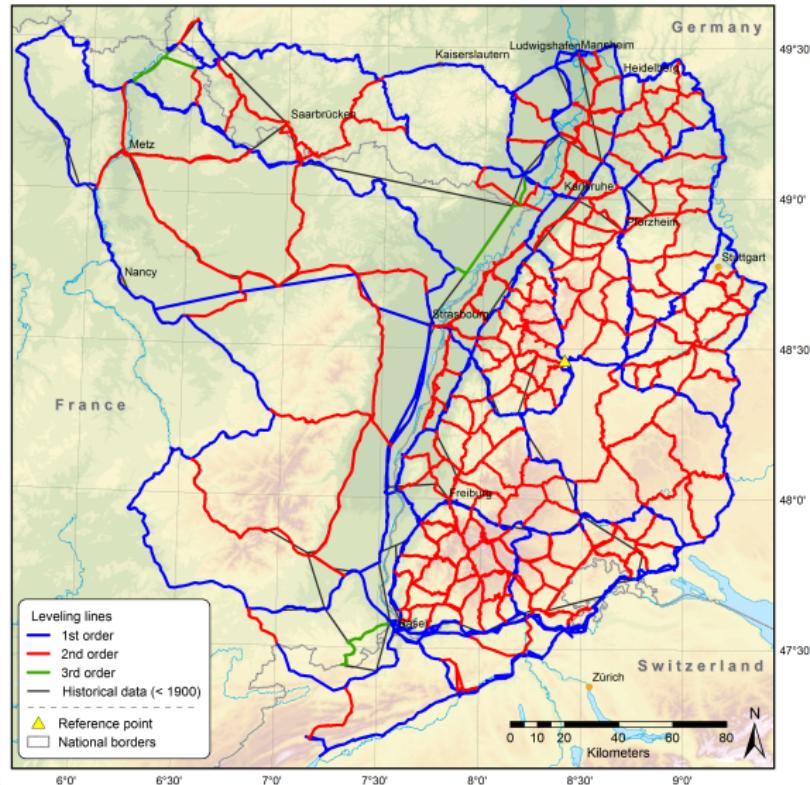
GeORG: www.geopotenziale.org



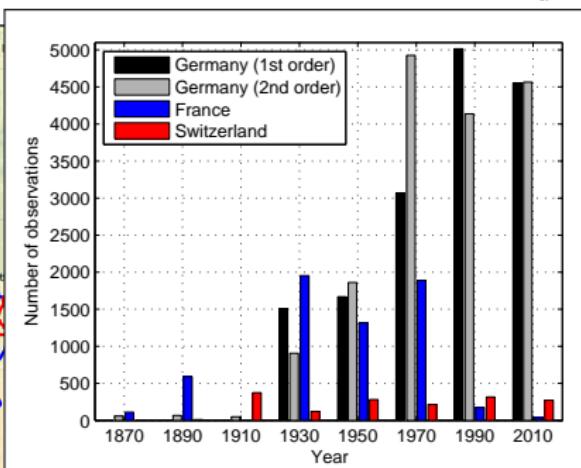
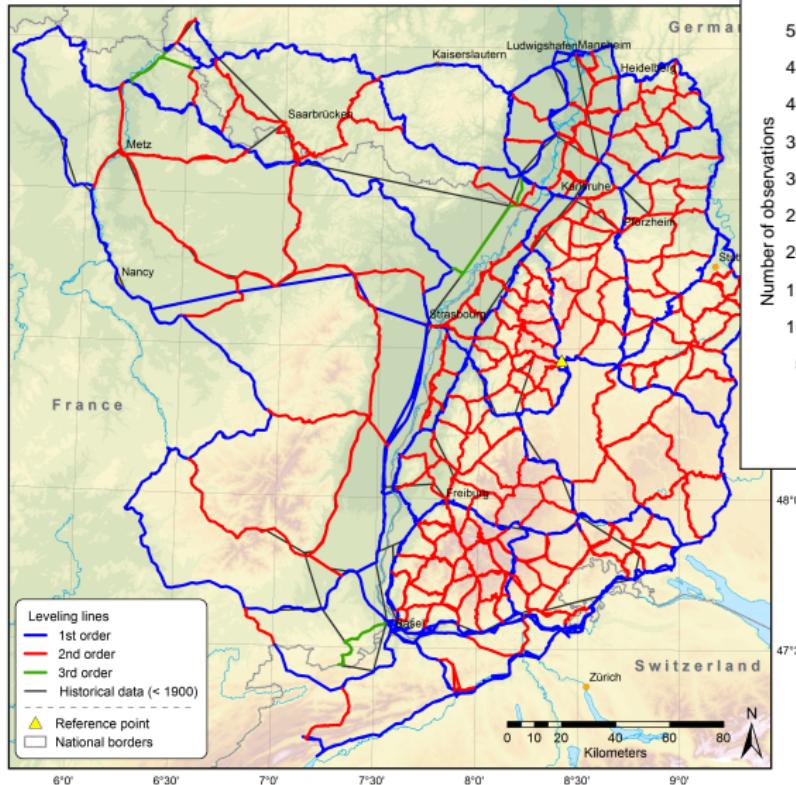




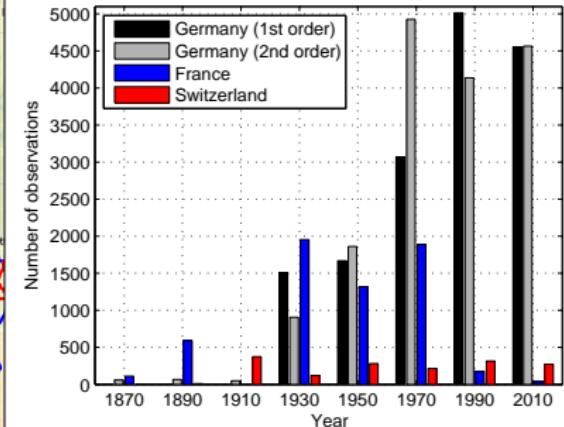
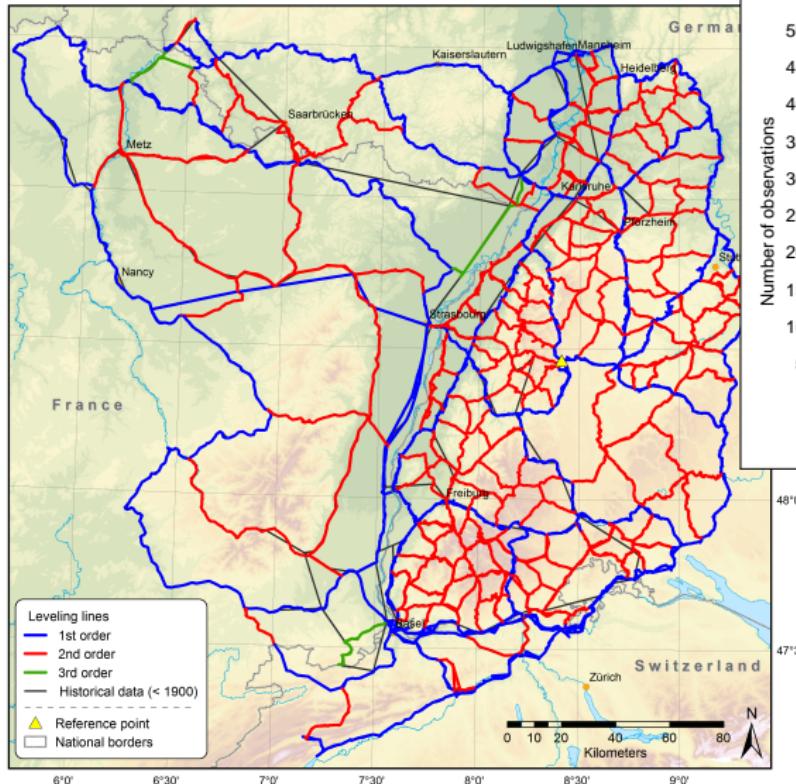
Levelling database



Levelling database



Levelling database



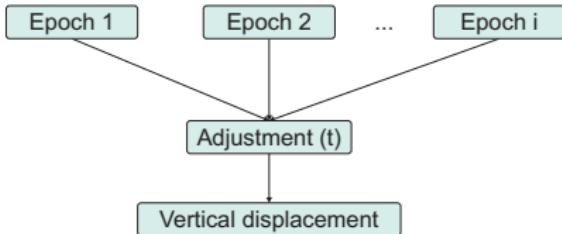
Adjustment

- 40049 observations (height differences)
- 15592 linear rates at levelling benchmarks

Kinematic adjustment approach

■ Basic equation:

$$H_{i,j} = H_{0,j} + \int_{t_0}^{t_i} \alpha_j dt$$
$$\approx H_{0,j} + v_{0,j} \Delta t_i + \frac{1}{2!} a_{0,j} \Delta t_i^2 + \dots$$



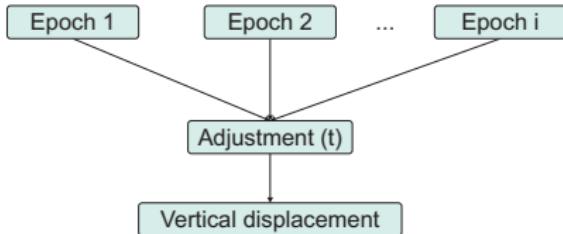
- Gauß-Markov model
- Relative observations:
Reference point needed

(Zippelt, 1988; Fuhrmann et al., TECTO, 2013)

Kinematic adjustment approach

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Parameters: Height

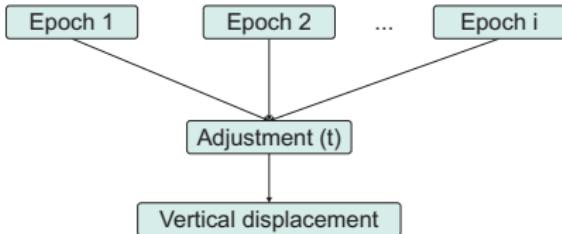
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Parameters: Height Velocity

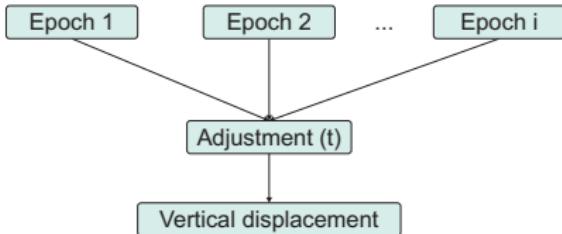
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Parameters: Height Velocity Acceleration

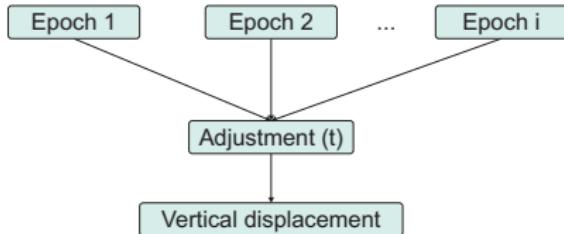
- Gauß-Markov model
- Relative observations:
Reference point needed

(Zippelt, 1988; Fuhrmann et al., TECTO, 2013)

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Parameters: Height Velocity Acceleration

■ Gauß-Markov model

$$I = A \begin{pmatrix} \hat{H} \\ \hat{v} \\ \hat{a} \end{pmatrix} + e$$

$$I = H_{i,(j,k)} - H_{i,(j,l)} \quad \text{Height differences}$$

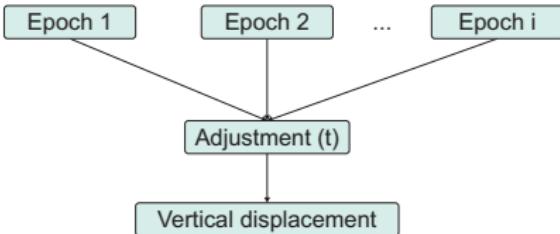
- Relative observations:
Reference point needed

(Zippelt, 1988; Fuhrmann et al., TECTO, 2013)

Kinematic adjustment approach

■ Basic equation:

$$H_{i,j} = H_{0,j} + \int_{t_0}^{t_i} \alpha_j dt$$
$$\approx H_{0,j} + v_{0,j} \Delta t_i + \frac{1}{2!} a_{0,j} \Delta t_i^2 + \dots$$



Parameters: Height Velocity Acceleration

■ Gauß-Markov model

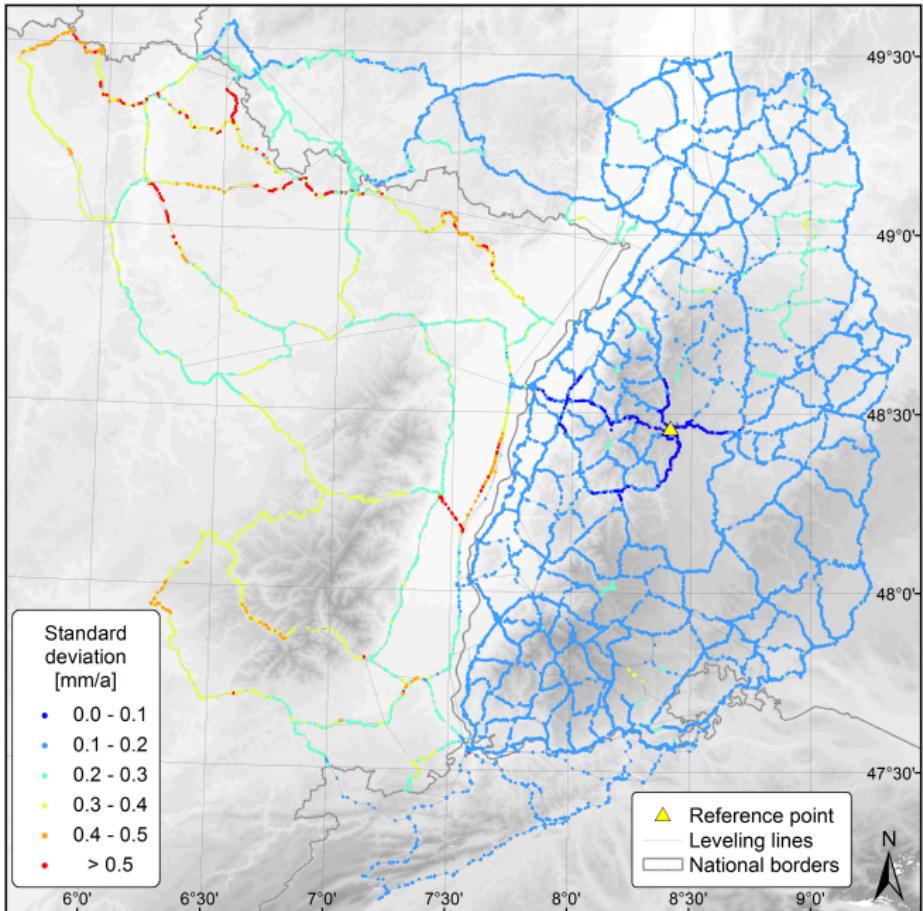
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$$I = H_{i,(j,k)} - H_{i,(j,l)} \quad \text{Height differences}$$

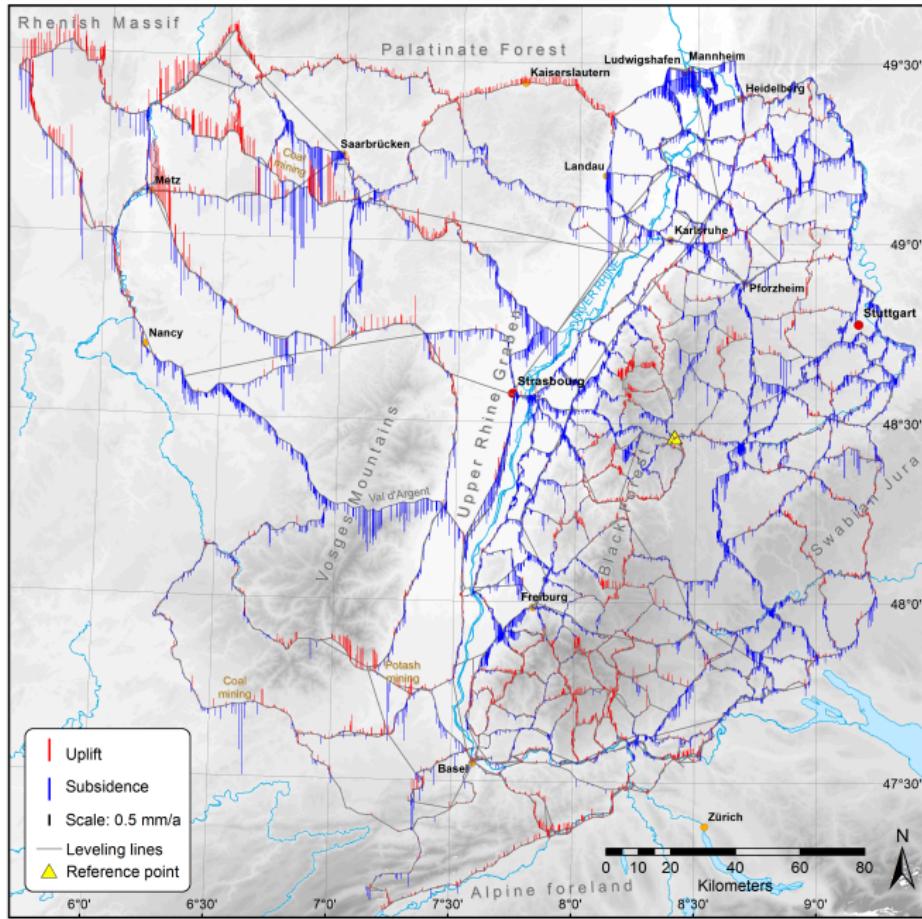
■ Relative observations: Reference point needed

$$\hat{H}_{ref} = const.$$
$$\hat{v}_{ref} = const. = 0$$

(Zippelt, 1988; Fuhrmann et al., TECTO, 2013)

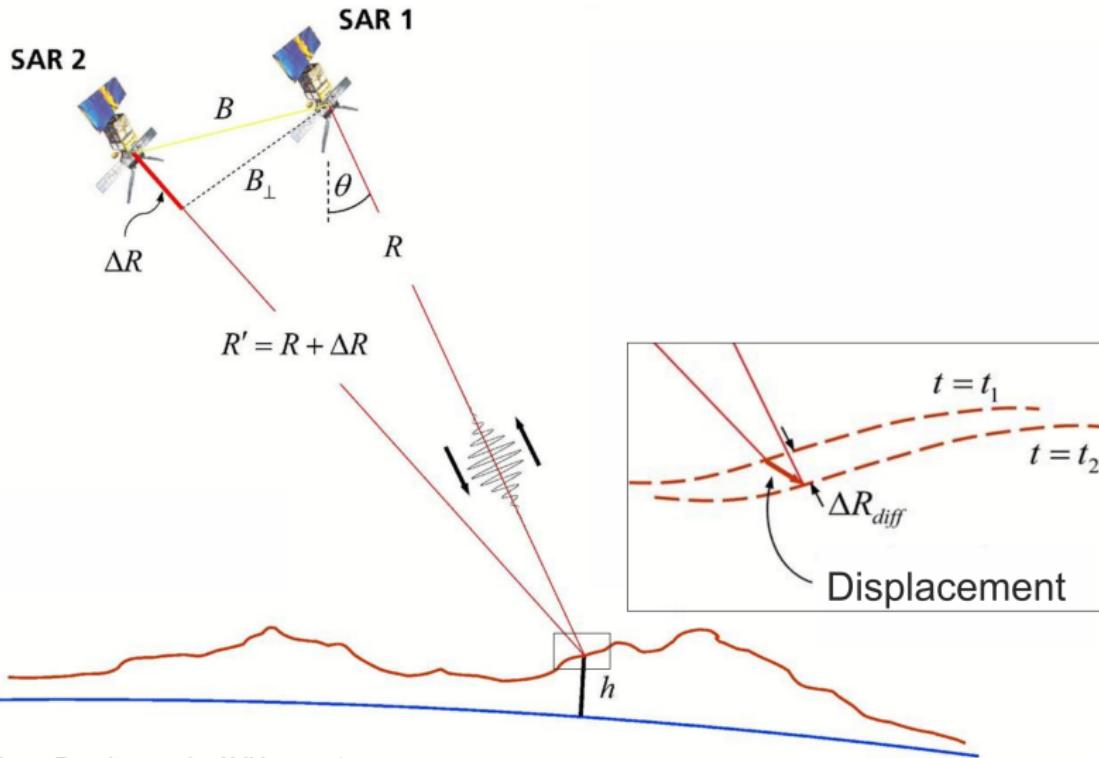


Standard
deviation of
linear rates:
 $\sigma_{\hat{v}}$



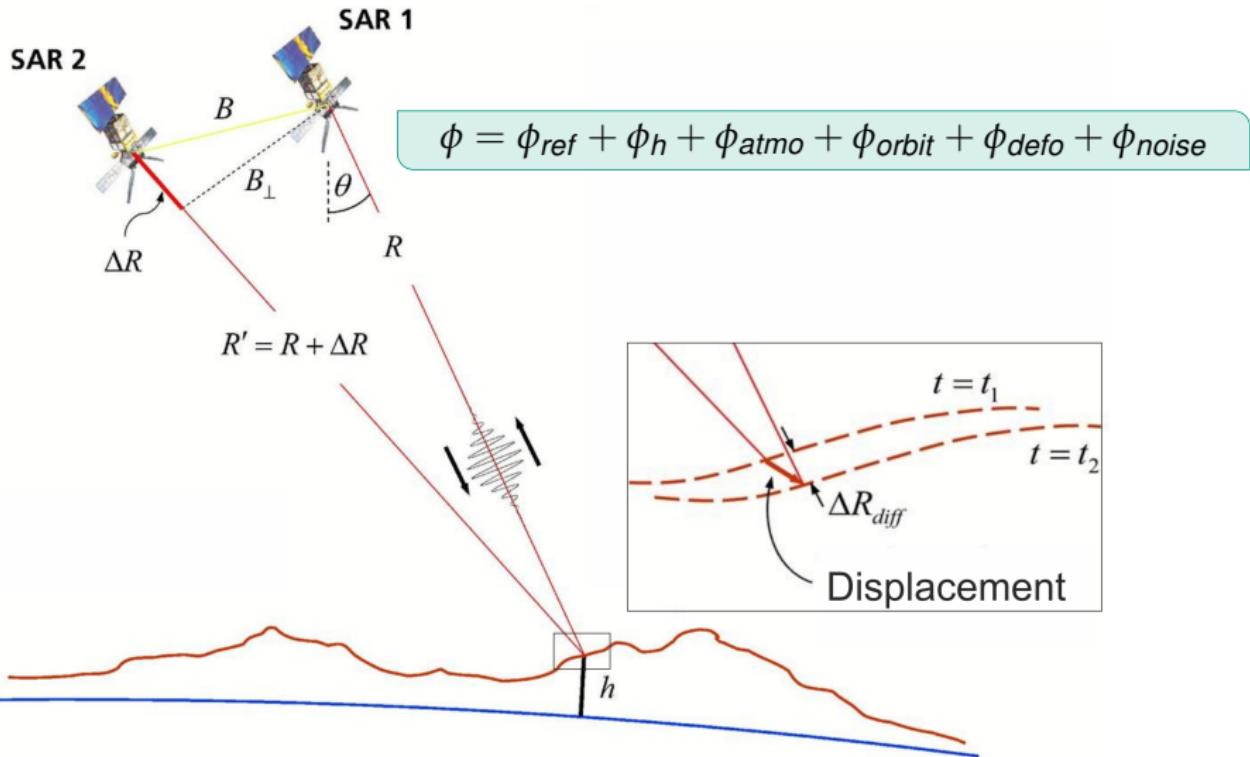
Linear rates:
 \hat{v}

SAR Interferometry (InSAR)

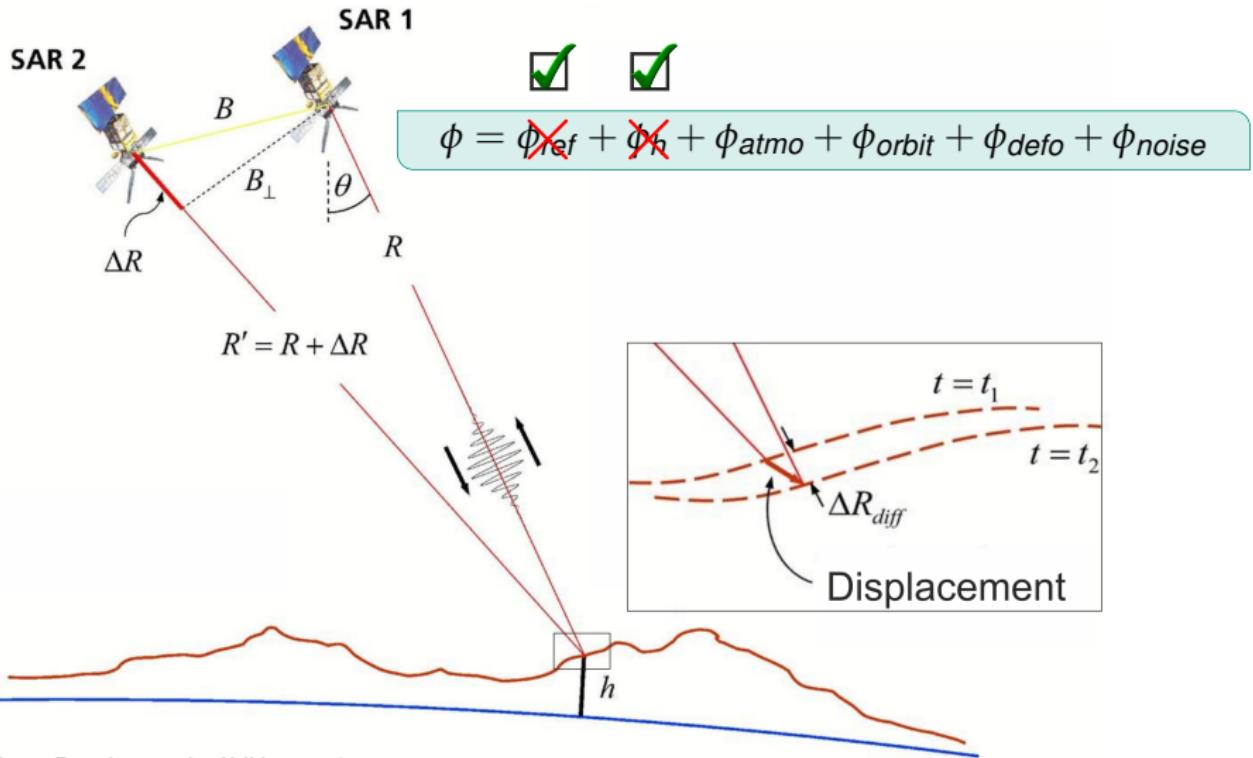


(from Bamler et al., AVN, 2008)

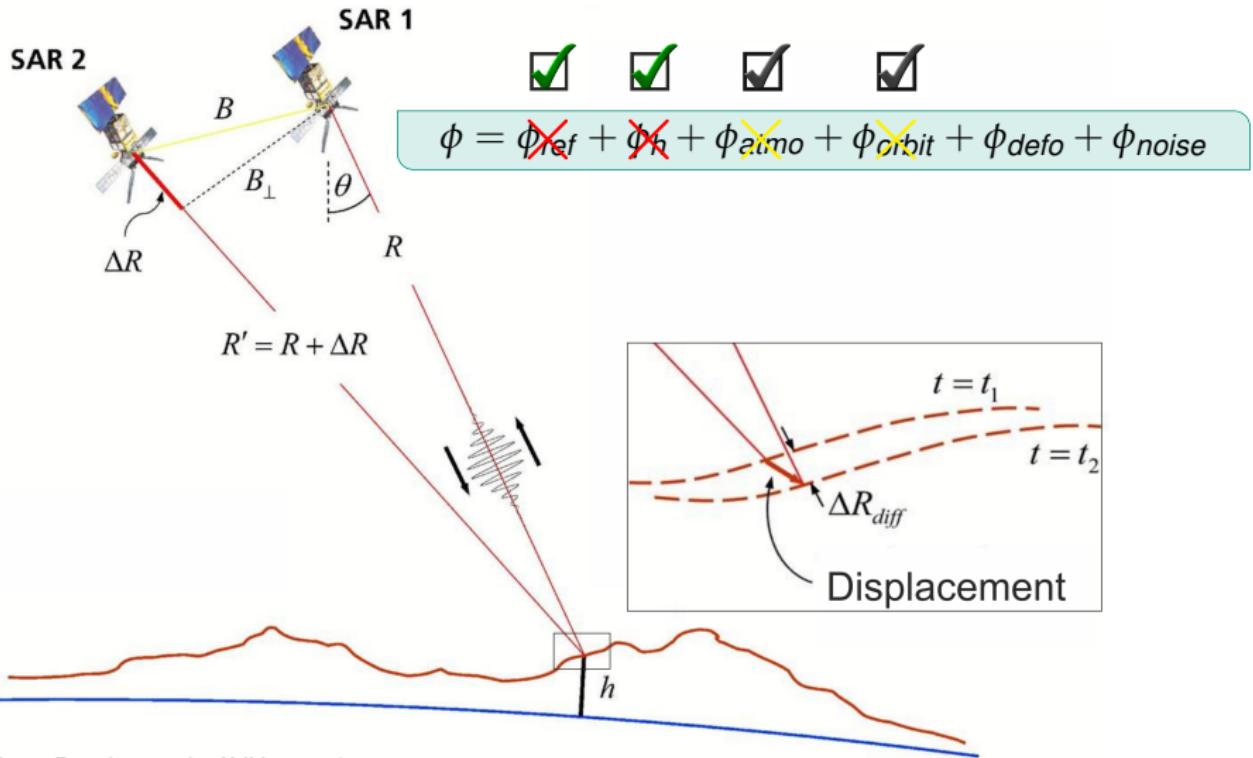
SAR Interferometry (InSAR)



SAR Interferometry (InSAR)

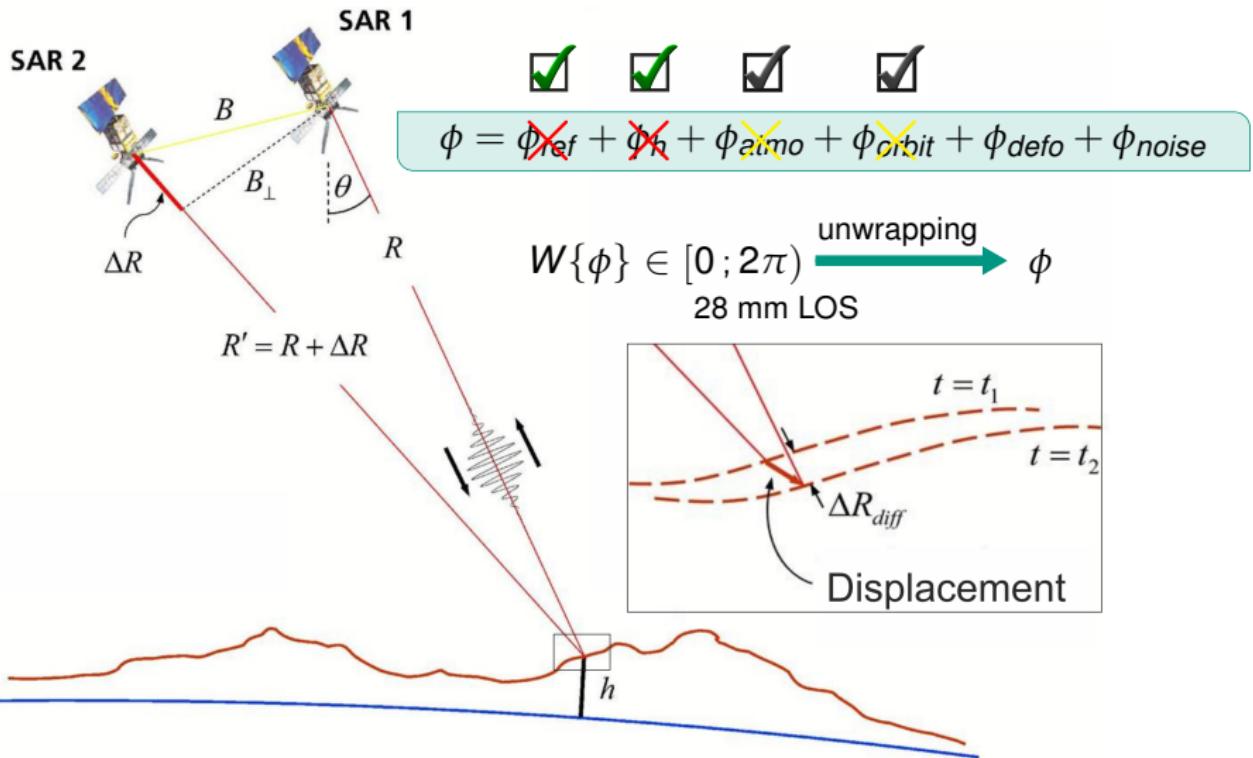


SAR Interferometry (InSAR)

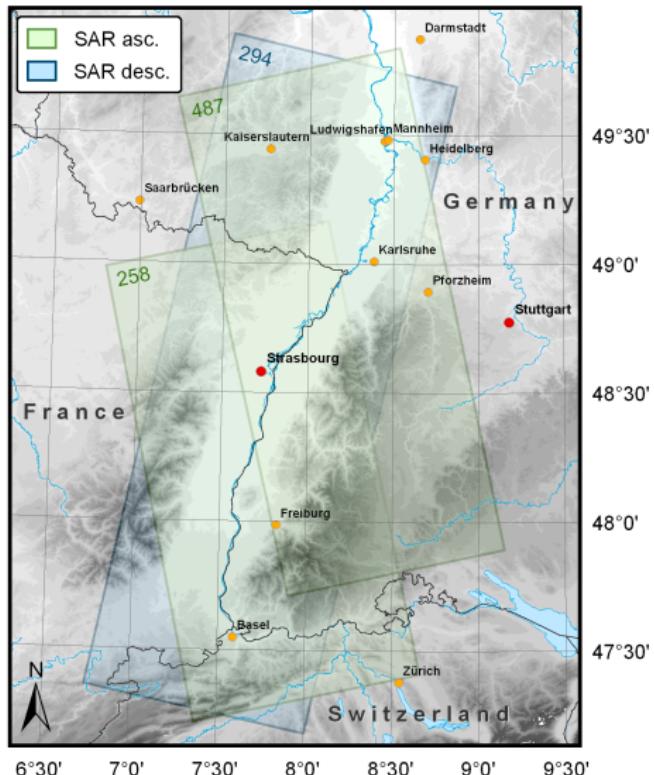


(from Bamler et al., AVN, 2008)

SAR Interferometry (InSAR)



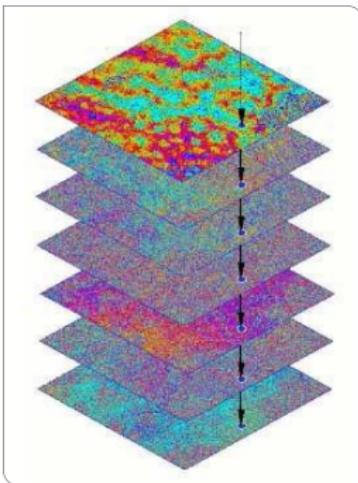
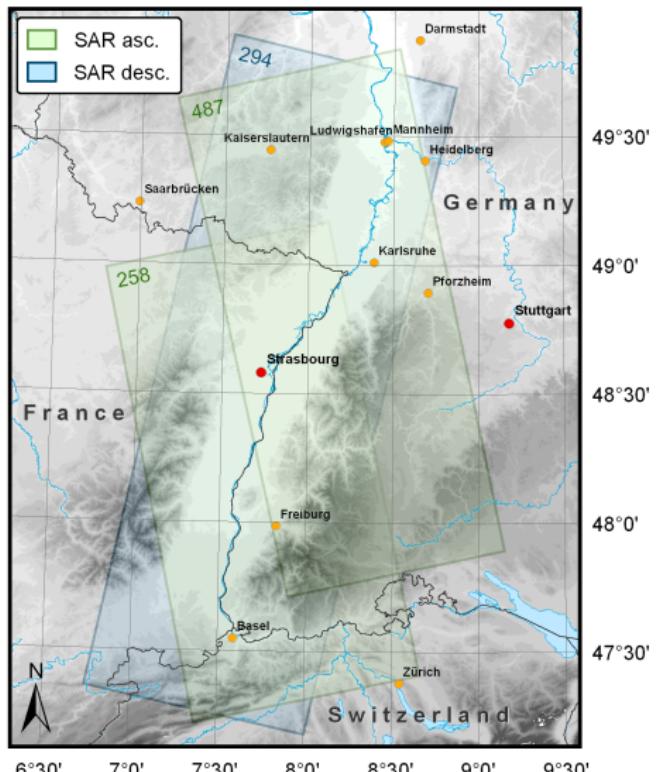
SAR database



Archived raw data:

Satellite	Track	Number of scenes		
		Stripe	North	South
ERS-1/2	294	69	70	69
	487	26	26	27
	258	tba	tba	tba
Envisat	294	16	18	44
	487	19	19	40
	258	tba	tba	tba

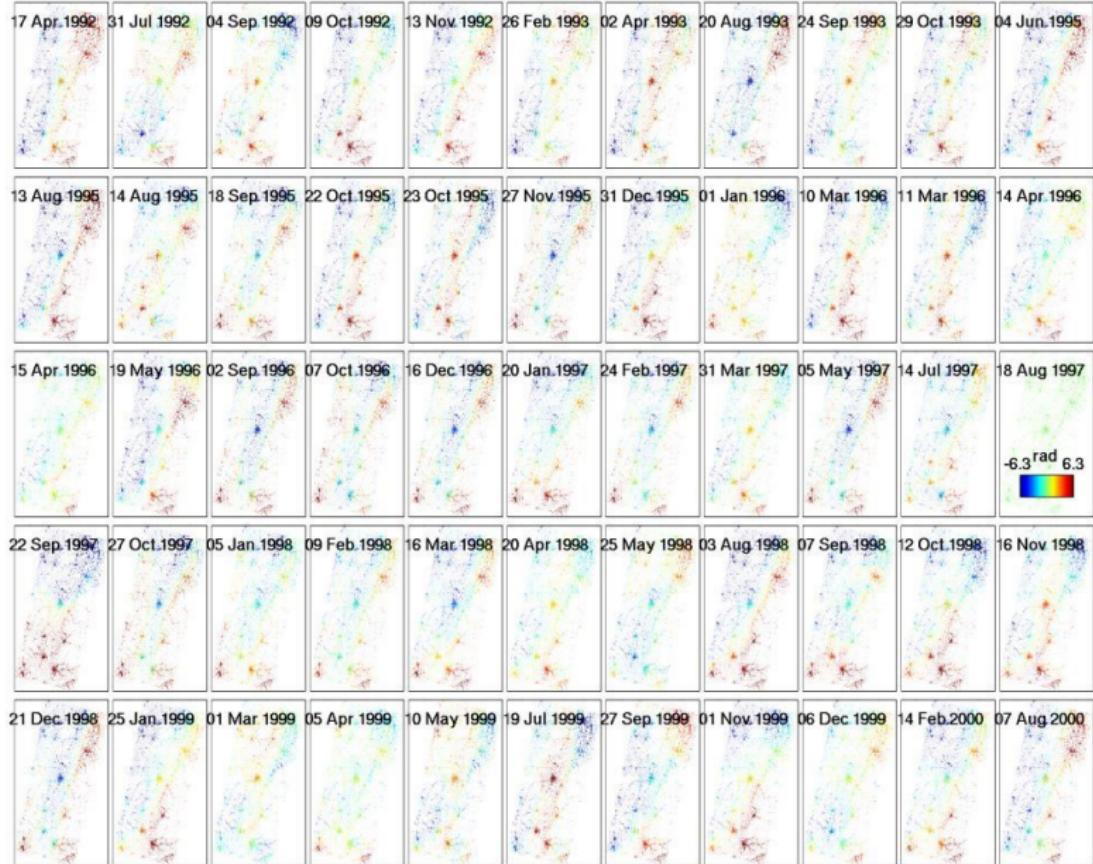
SAR database



Persistent
Scatterer
(Hooper et al.,
JGR, 2007)

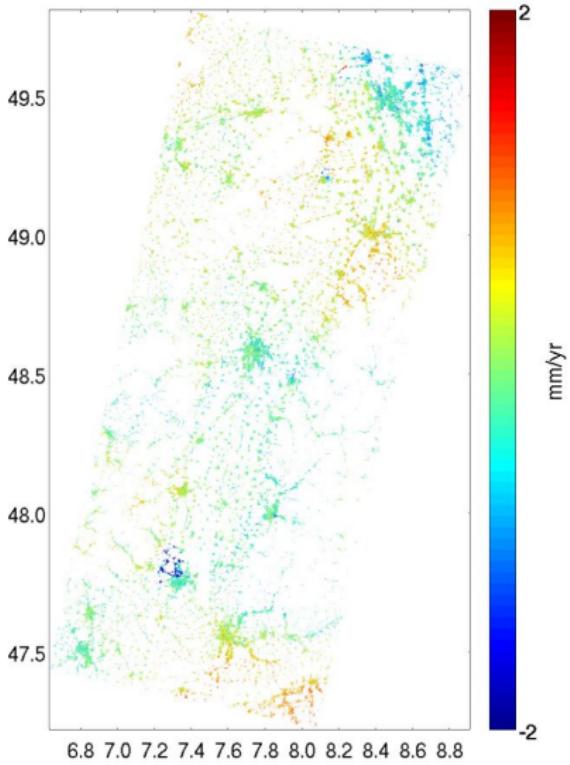
Archived raw data:

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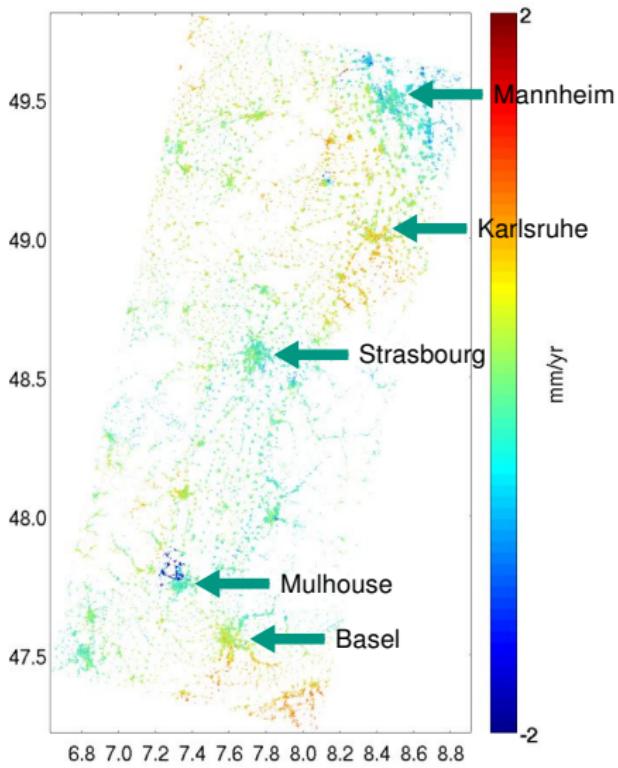


ERS track
294, 54 inter-
ferograms,
Unwrapped
phase

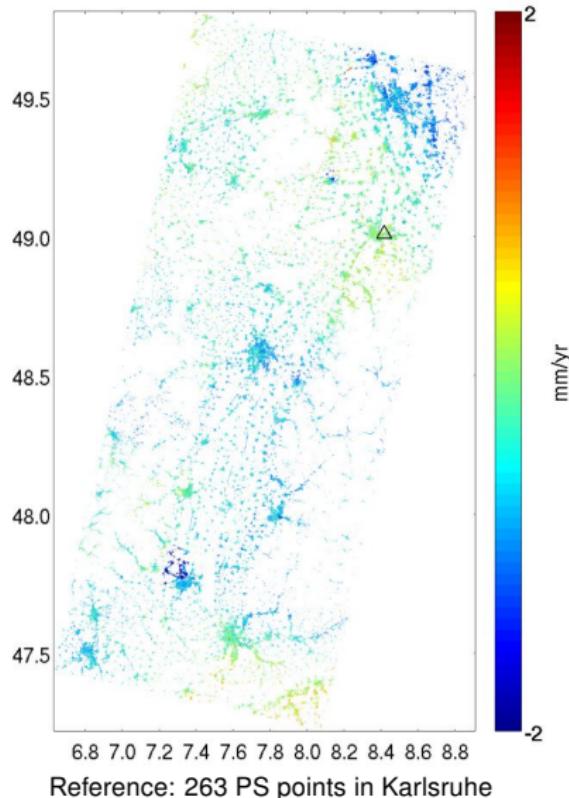
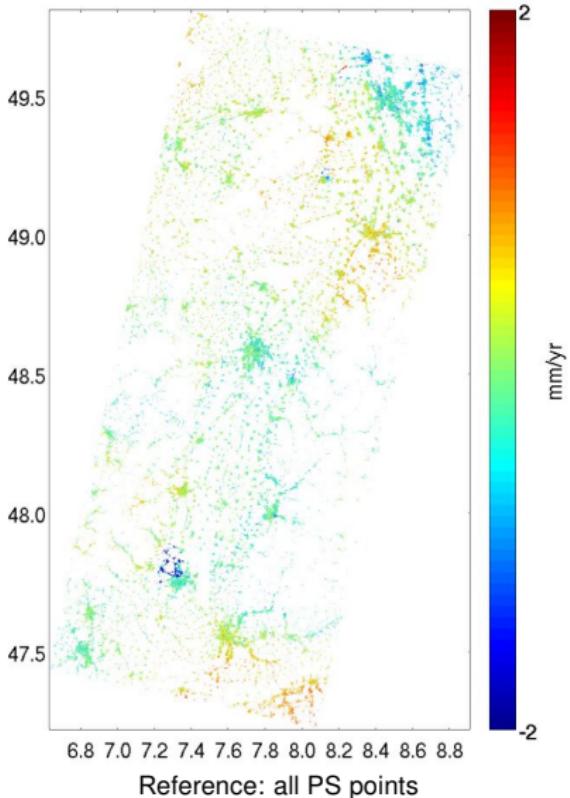
Mean LOS velocity at 677,951 PS points

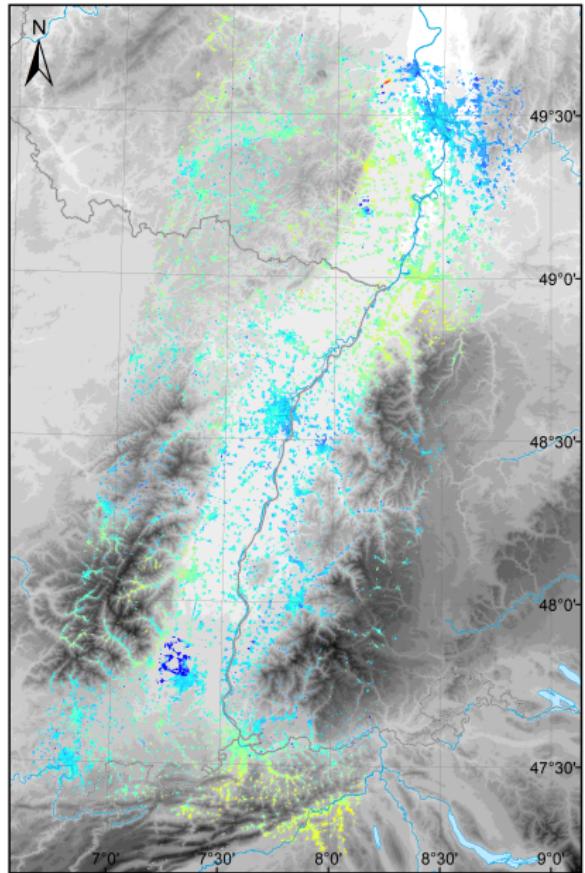


Mean LOS velocity at 677,951 PS points

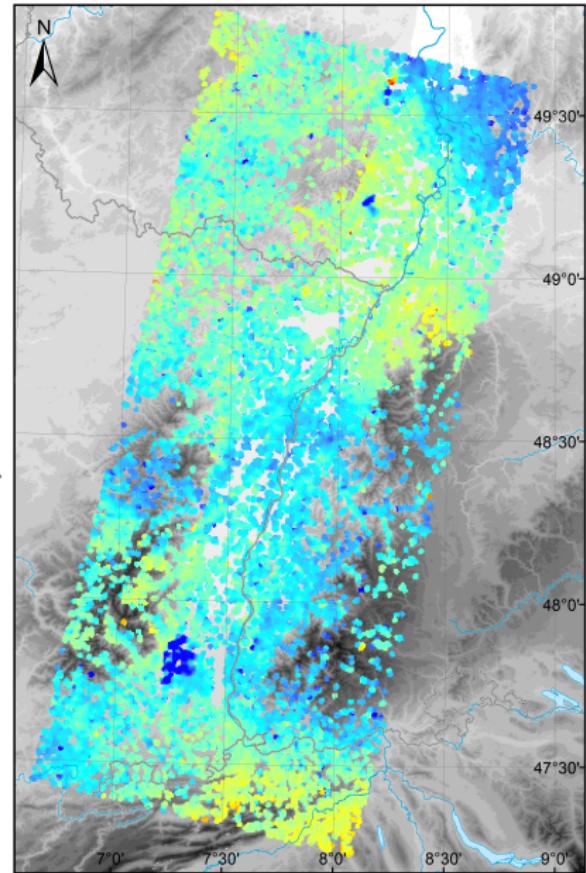


Mean LOS velocity at 677,951 PS points

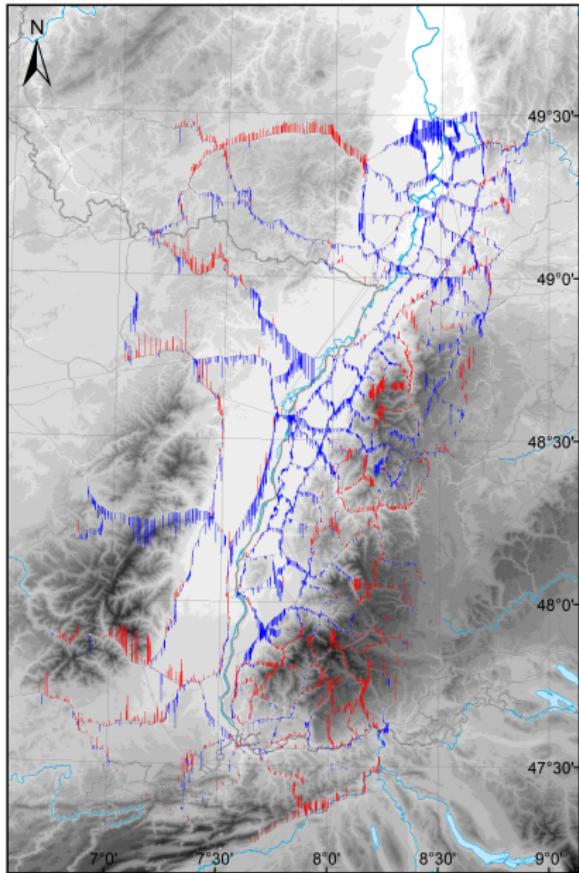




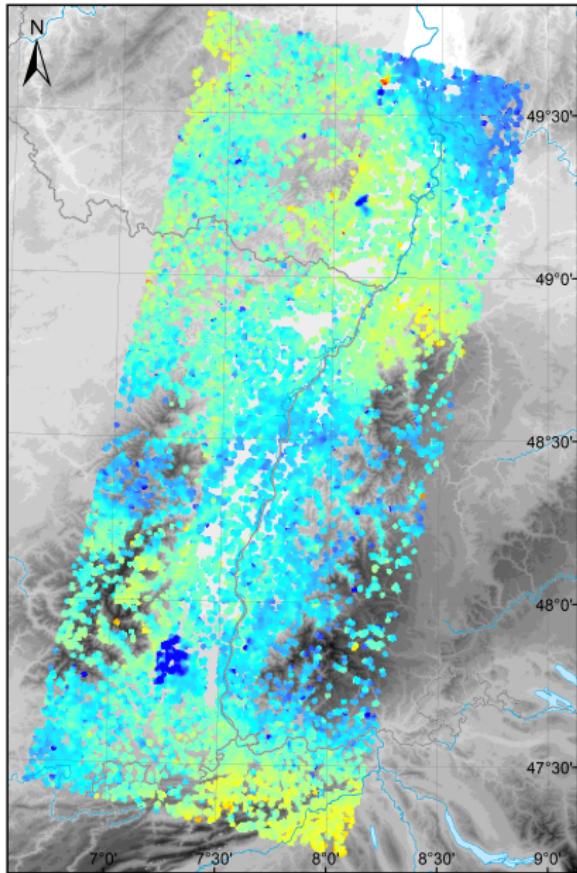
LOS velocities interpolated to 100 m grid



LOS velocities interpolated to 500 m grid

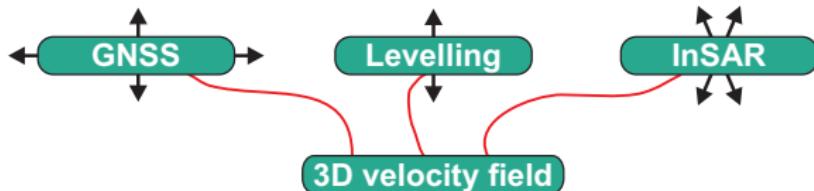


Vertical velocities from levelling analysis



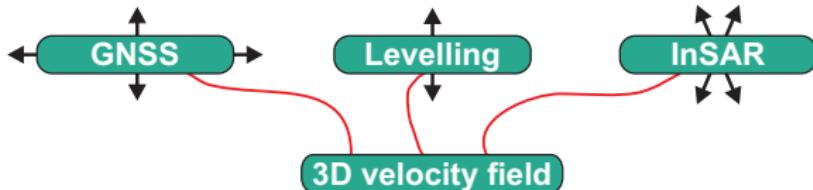
LOS velocities interpolated to 500 m grid

Combination



- Interpolation of velocities V_{LOS} , $V_{GNSS,x}$, $V_{GNSS,y}$, V_{Lev} on a common grid
- Derivation of a 3D velocity field (v_x , v_y , v_z)

Combination

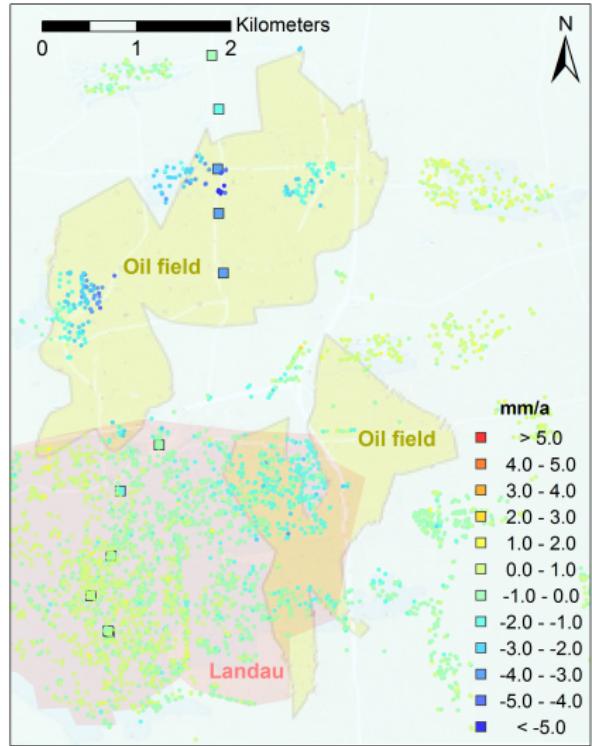


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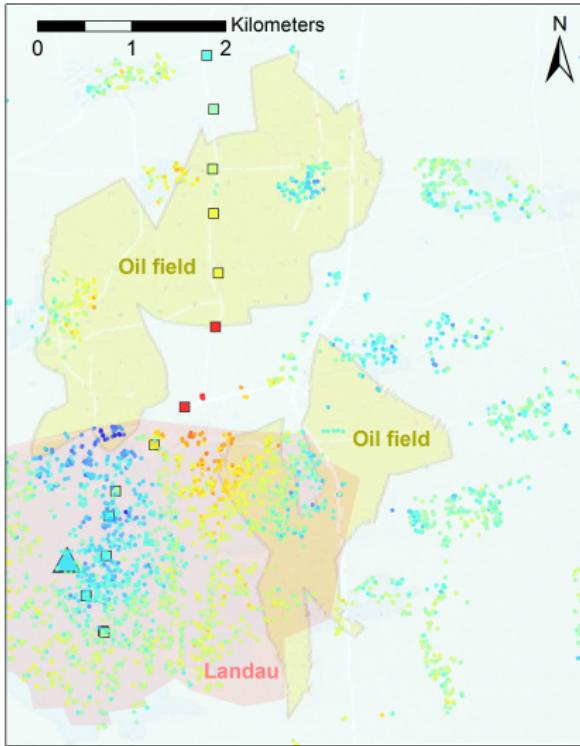
$$U(v_x, v_y, v_z) = \sum_{i=1}^N \left\{ \frac{1}{2(\sigma_{LOS}^i)^2} \left(V_{LOS}^i - S_x^i v_x - S_y^i v_y - S_z^i v_z \right)^2 + \frac{1}{2(\sigma_{GNSS,x}^i)^2} \left(V_{GNSS,x}^i - v_x \right)^2 + \frac{1}{2(\sigma_{GNSS,y}^i)^2} \left(V_{GNSS,y}^i - v_y \right)^2 + \frac{1}{2(\sigma_{Lev}^i)^2} \left(V_{Lev}^i - v_z \right)^2 \right\}$$

(according to Hu et al., ISIDF, 2011)

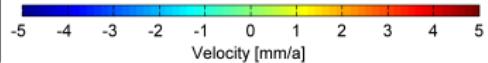
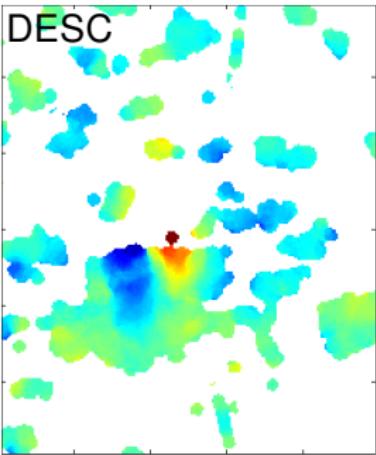
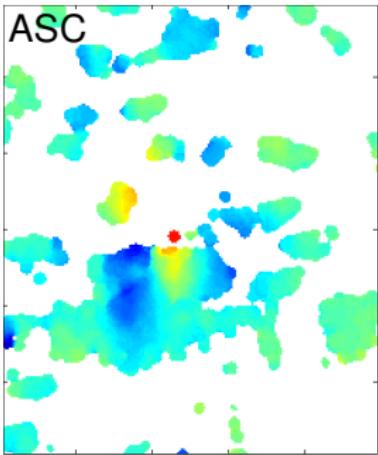
Case study – City of Landau

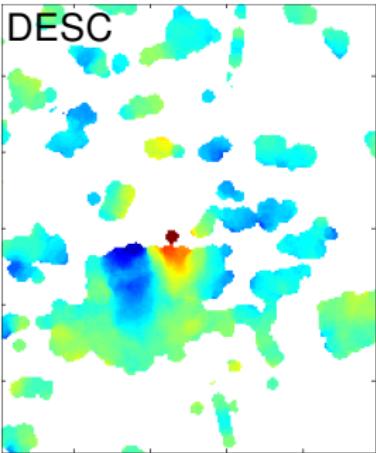
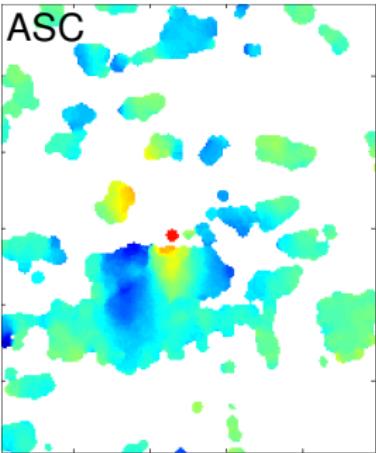


ERS-1/2: 1992–2000, Lev.: 1994 and 2003



Envisat: 2003–2008, Lev.: 2003 and 2009

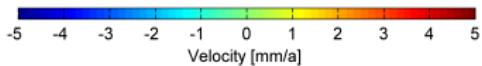


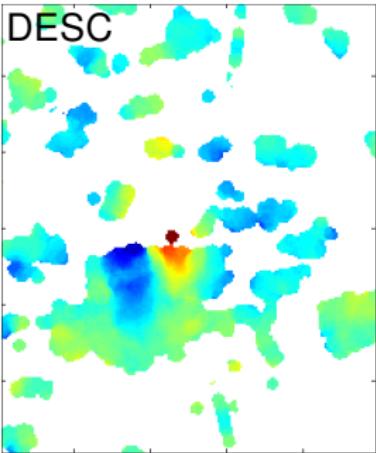
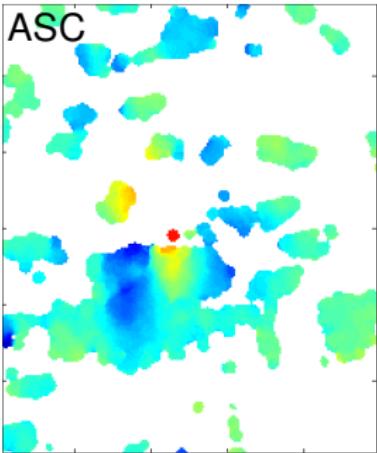


$$\begin{pmatrix} v_{asc} \\ v_{desc} \end{pmatrix} = S(\theta, \alpha) \cdot \begin{pmatrix} v_{up} \\ v_{east} \end{pmatrix}$$

θ : Satellite incidence angle

α : Satellite heading

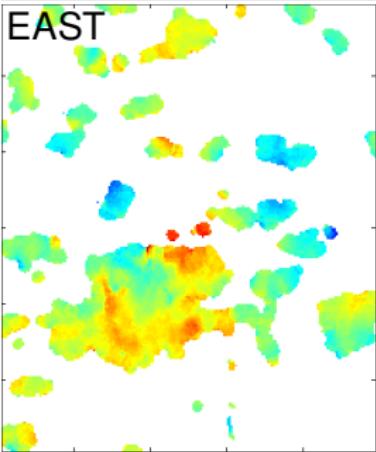
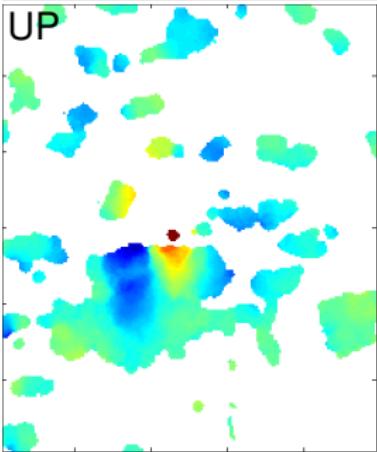
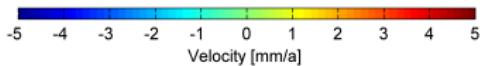


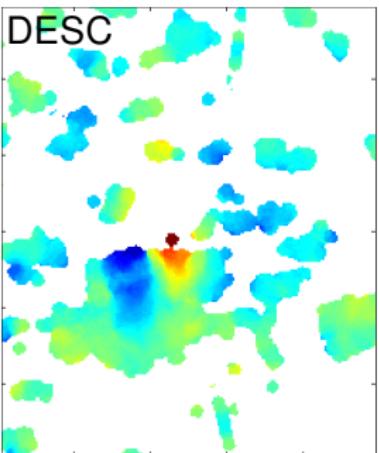
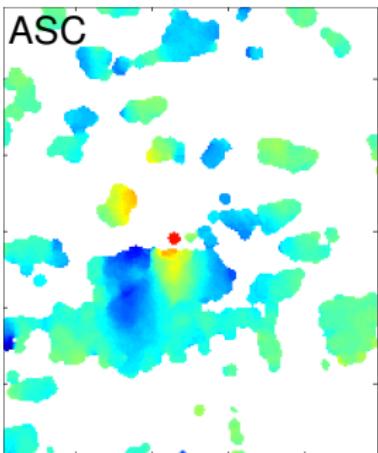


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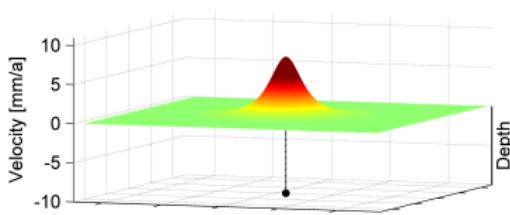
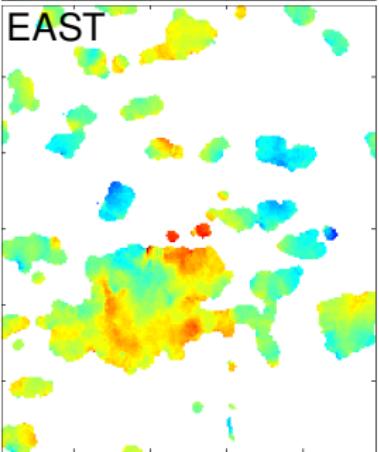
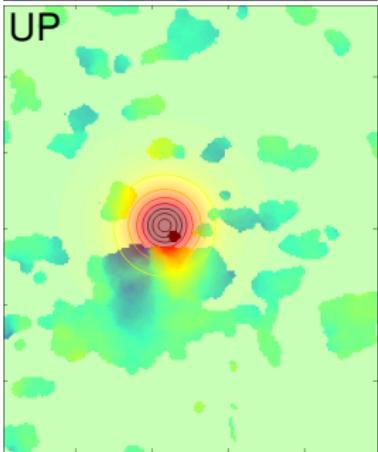
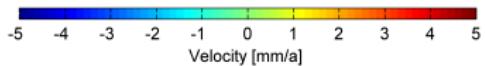




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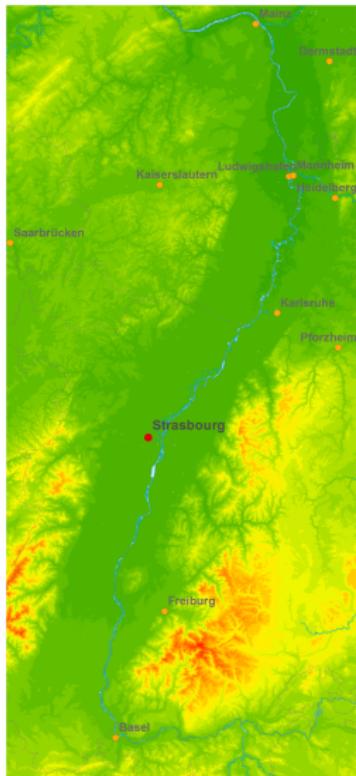
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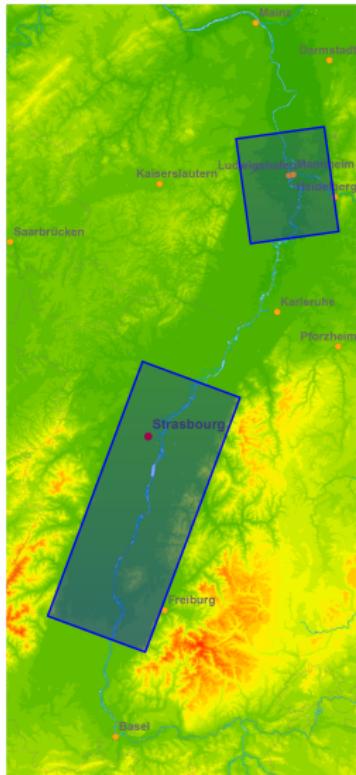
Uplift corresponds to a Mogi point source at 800 m depth with 20000 m³ volume change

Summary



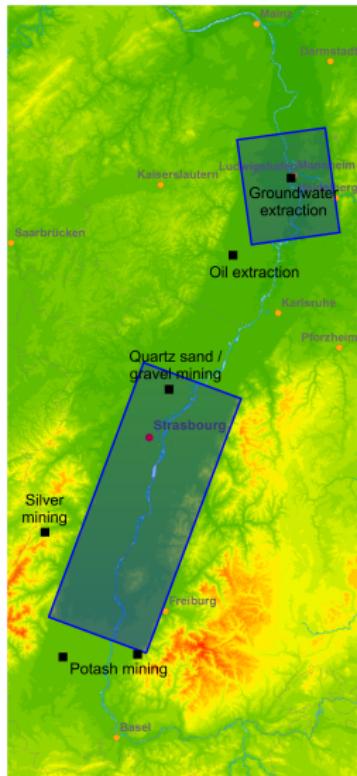
- Relative vertical movement of URG w.r.t. Graben shoulders of about 0.5 mm/a
- Relative subsidence of Strasbourg/Freiburg region w.r.t. Karlsruhe region
- Relative subsidence of Northern URG w.r.t. Karlsruhe region, purely anthropogenic?
- Man-made displacements with different temporal and spatial extent
- Monitoring of exploitation areas from space
→ Sentinel 1

Summary



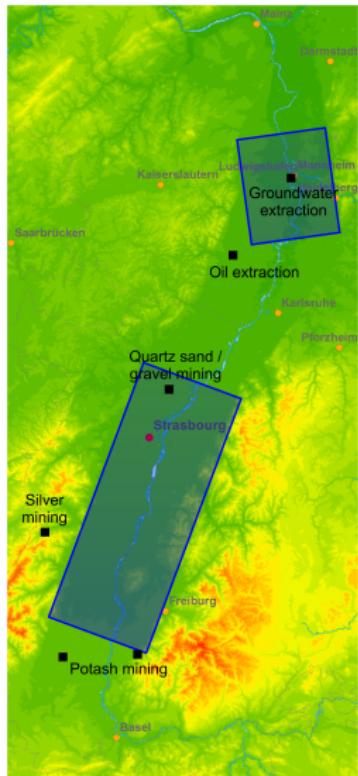
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