Surface deformations observed by GPS and its relation to groundwater variations in France

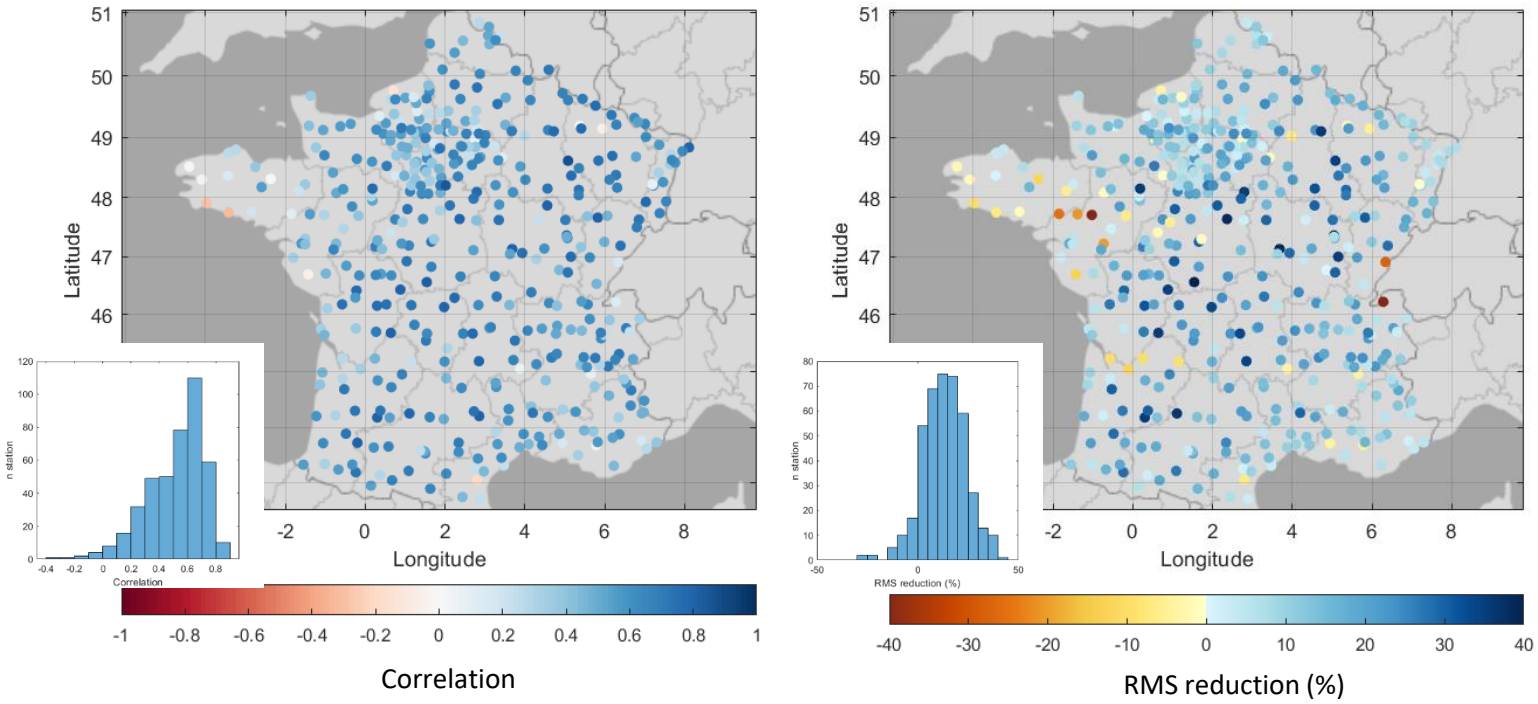
Anita Thea Saraswati[1], Tonie van Dam[2,3], Kuei-Hua Hsu[4], Annette Eicker[4]

[1]University of Luxembourg, Esch-sur-Alzette, Luxembourg; [2]Interdisciplinary Centre for Security, Reliability and Trust, University of Luxembourg, Luxembourg; [3]University of Utah, Salt Lake City, UT, United States; [4]Geodesy & Geoinformatics, HafenCity University Hamburg, Hambourg, Germany

GPS observations have already been demonstrated to be sensitive to the elastic deformation associated with changes in hydrological loading (e.g. van Dam et al., 2001)

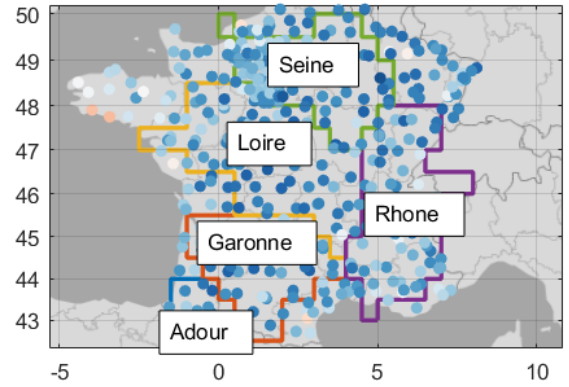
Data:
- GPS solutions from NGL (Blewitt et al., 2018)
- Groundwater boreholes from French National Portal of groundwater (https://ades.eaufrance.fr/)
- GW x porosity x ρ_{H_2O} = EWH

Converting surface loading into displacements
To be compared with GNSS vertical displacements, surface loadings from the in-situ groundwater are converted into displacements using Green's functions approach (Farrell, 1972)



- GPS sites in France are dominated by elastic loading
- At most of the sites, observed displacements by GPS can be explained by the variability of groundwater changes

Subbasin	Mean Correlation	Stations with correlation>0.6 (%)	Mean RMS reduction (%)
Adour	0.58	50%	17.30
Garonne	0.58	55%	15.67
Loire	0.57	56%	17.03
Rhone	0.52	37%	11.90
Seine	0.52	41%	14.86



European Geosciences Union
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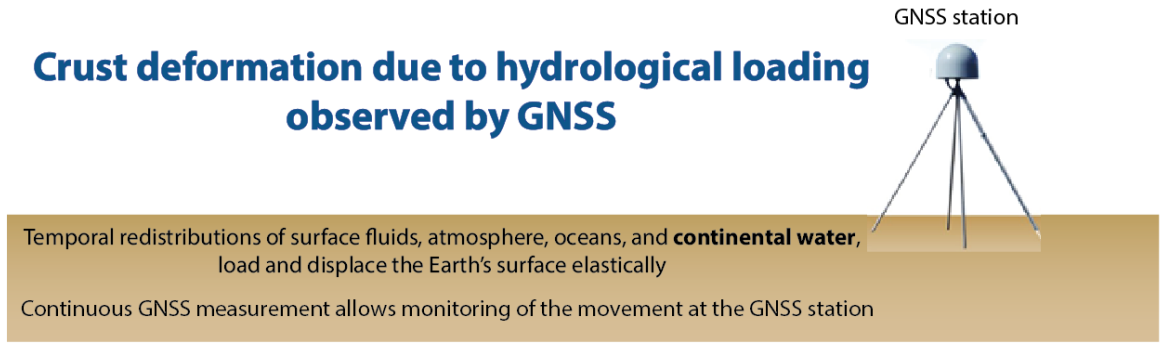
Background

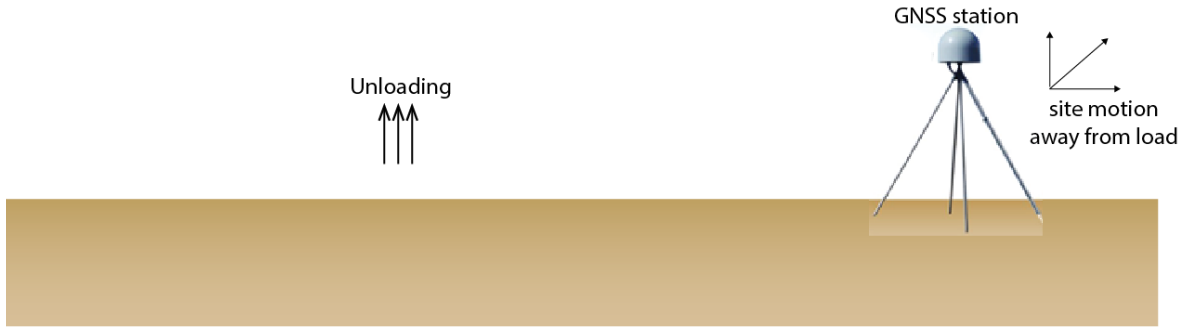
- GPS observations have already been demonstrated to be sensitive to the elastic deformation associated with changes in hydrological loading (e.g. van Dam et al., 2001)
- Using loading theory (Farrell, 1972), the predicted vertical surface displacements due to water changes on the Earth can be determined.

Motivation

To understand the displacement observed by GPS and its relation with the groundwater vatiation

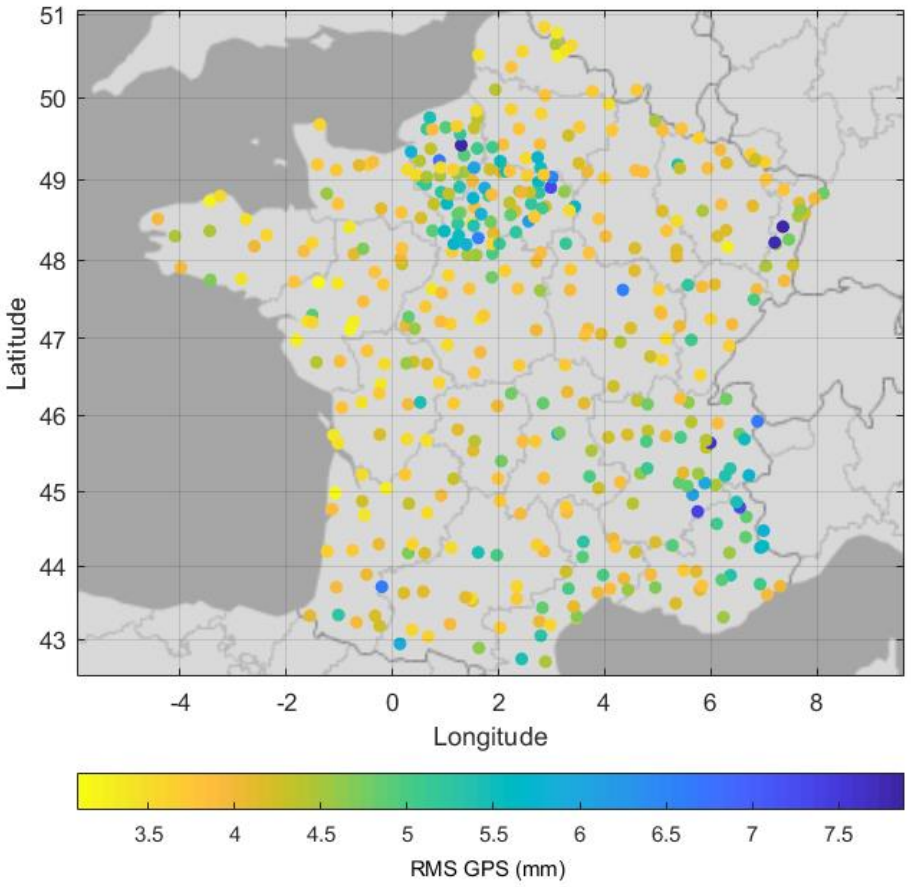
Understanding the nature of the observed GPS displacements related to the continental water variations is important to help identify which compartment in the total water storage controls the water changes in any particular region.





Data

GPS position time series



- 420 GPS stations
- GPS daily solutions from Nevada Geodetic Laboratory (NGL) (Blewitt et al., 2018)
- NTAL and NTOL are removed from the solutions from GFZ loading grid (Dill & Dobslaw, 2013)
- Stations velocity and discontinuities are removed
- Daily GPS time series are averaged into monthly solutions

Data

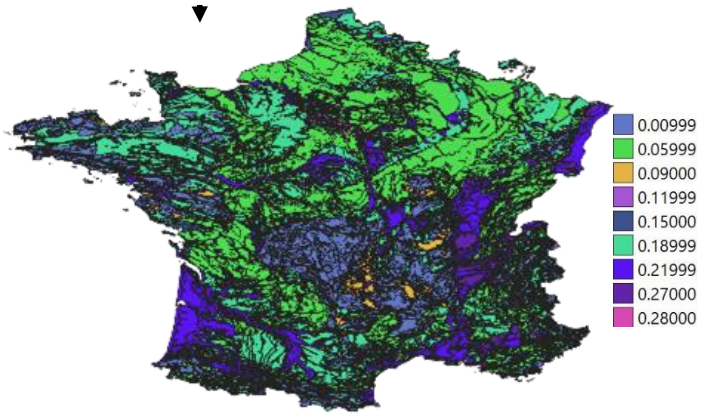
Groundwater borehole in France

- ~3200 unconfined boreholes From French National Portal of groundwater (GW) (https://ades.eaufrance.fr/)
- Porosity from GLHYMPS (Gleeson et al, 2014)
- GW x porosity x ρ_{H_2O} = EWH

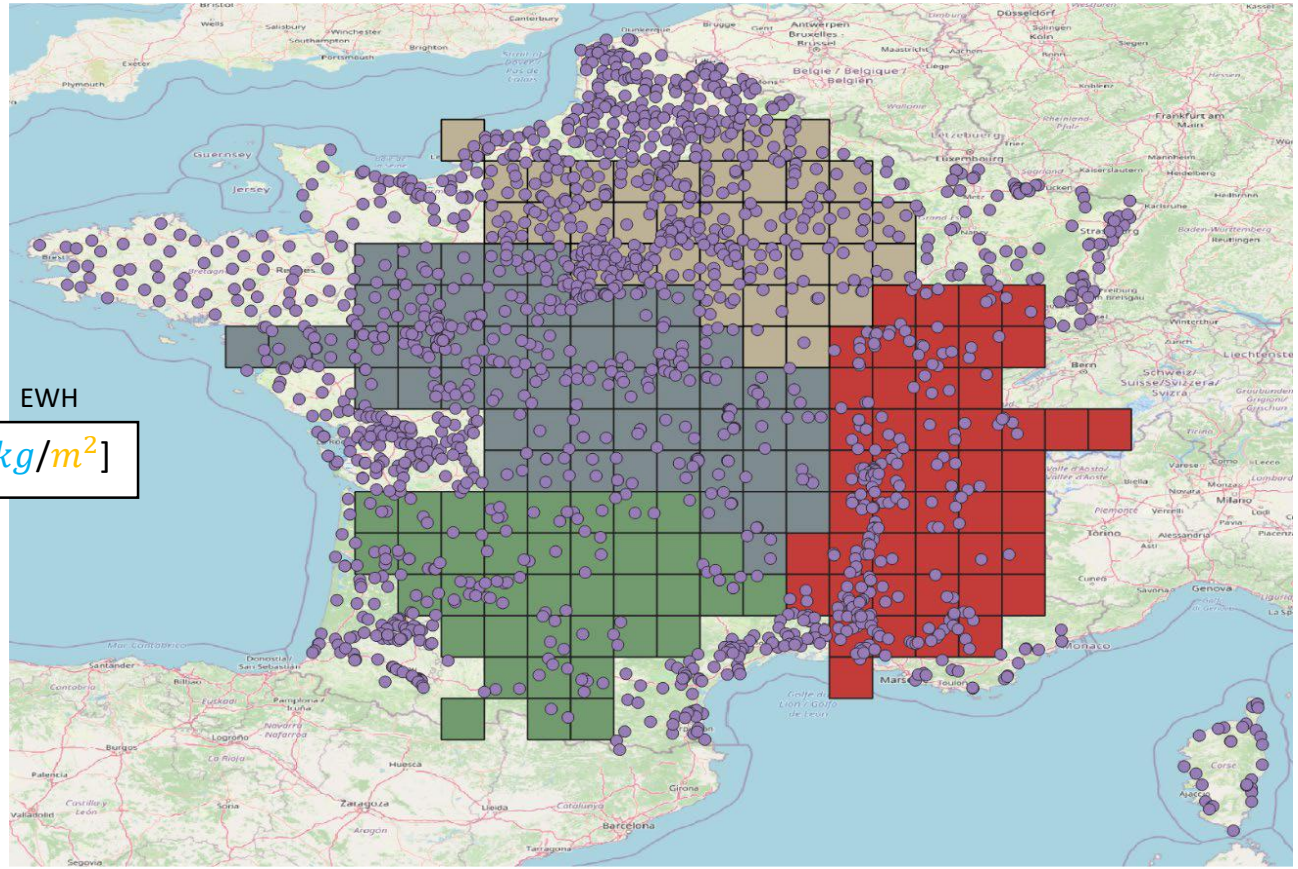
GW borehole unit

GW head variation $[m]$ * Porosity [unitless] * Water density 1000 $[kg/m^3]$ = EWH $[kg/m^2]$

Mean of timeseries GW head

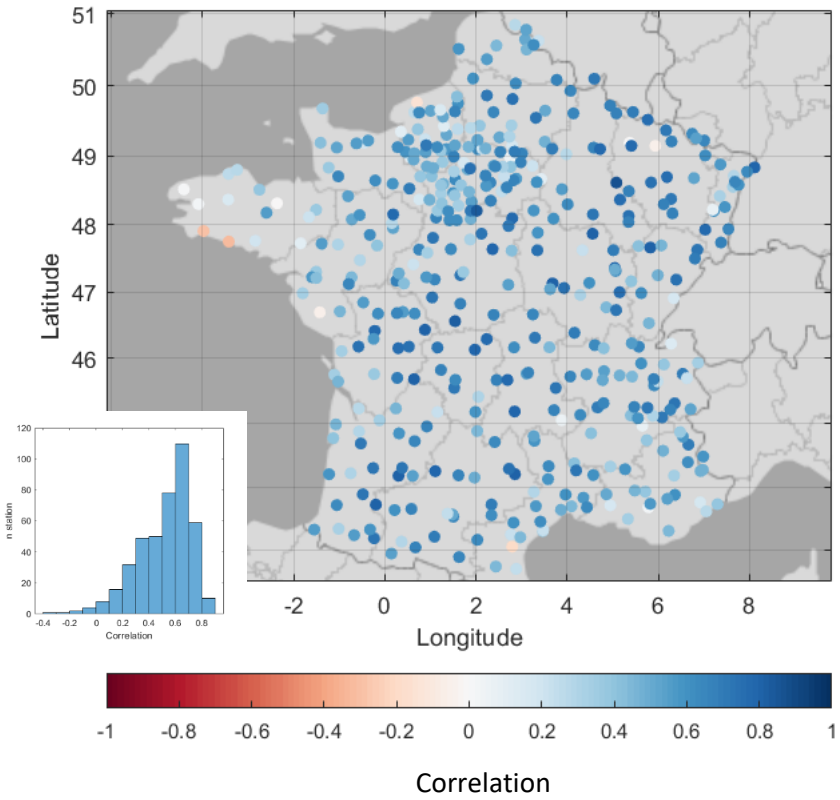


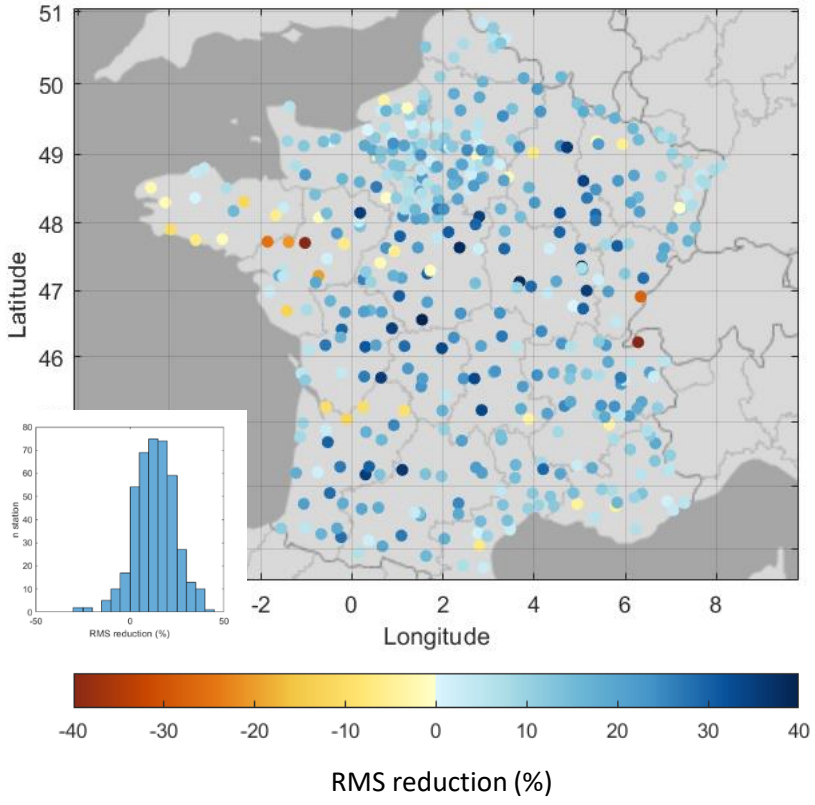
Gleeson et. al (2014)



See Hsu et al., EGU21-1317, Session HS2.5.1

Comparing height GPS vs modelled from GW-borehole





(Left) Correlation between GPS height time series and modelled displacement due to observed groundwater.
(Right) Reduction in scatter of GPS height time series (in percentage) after removing effect from groundwater borehole measurements.

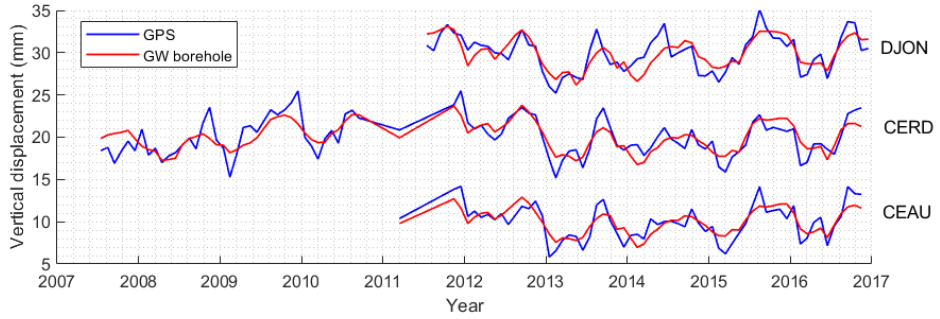
\+ RMS reduction: better fit
\- RMS reduction: less fit

correlation > 0.6=43% stations
Mean correlation=0.5151

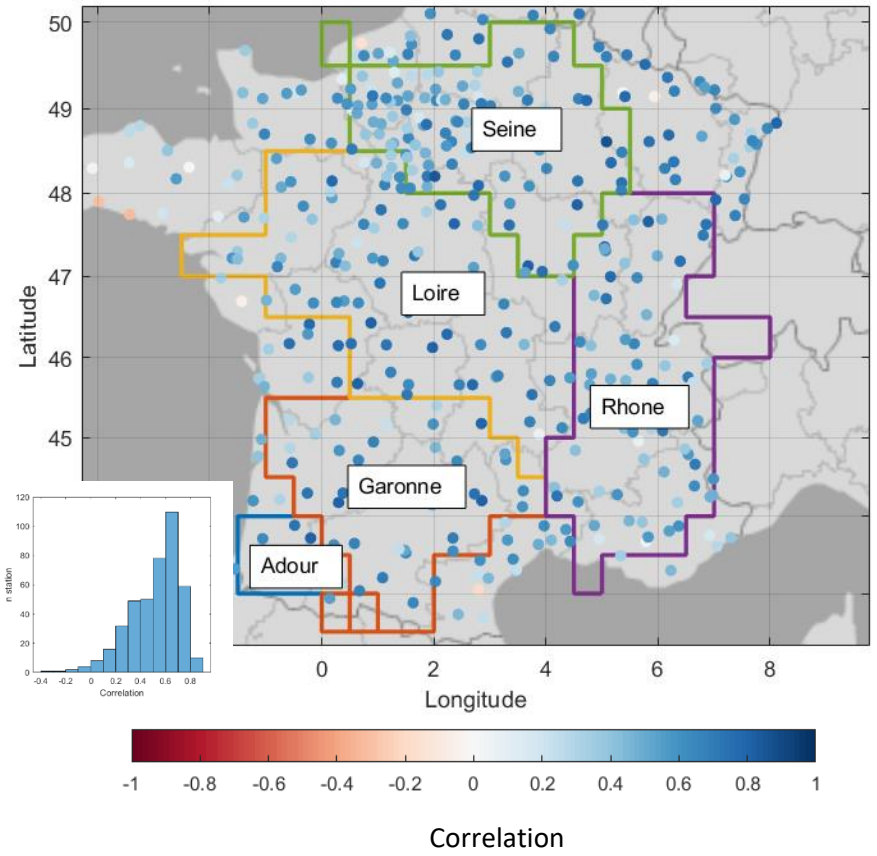
91% stations has positive RMS reduction
Mean RMS red=12.89%

could indicate

GPS sites in France are dominated by elastic loading



Statistics for each sub-basin



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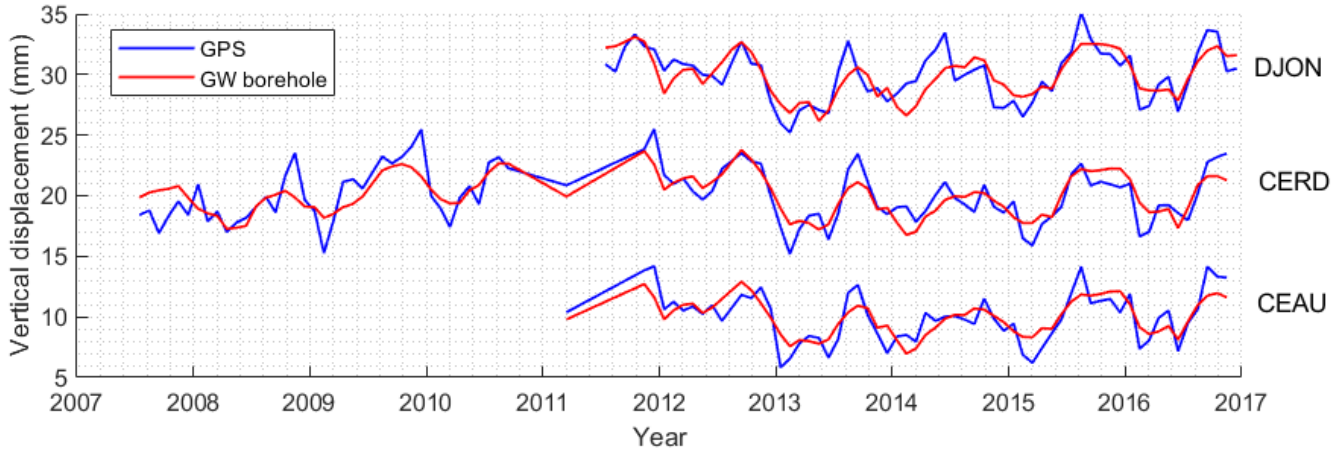
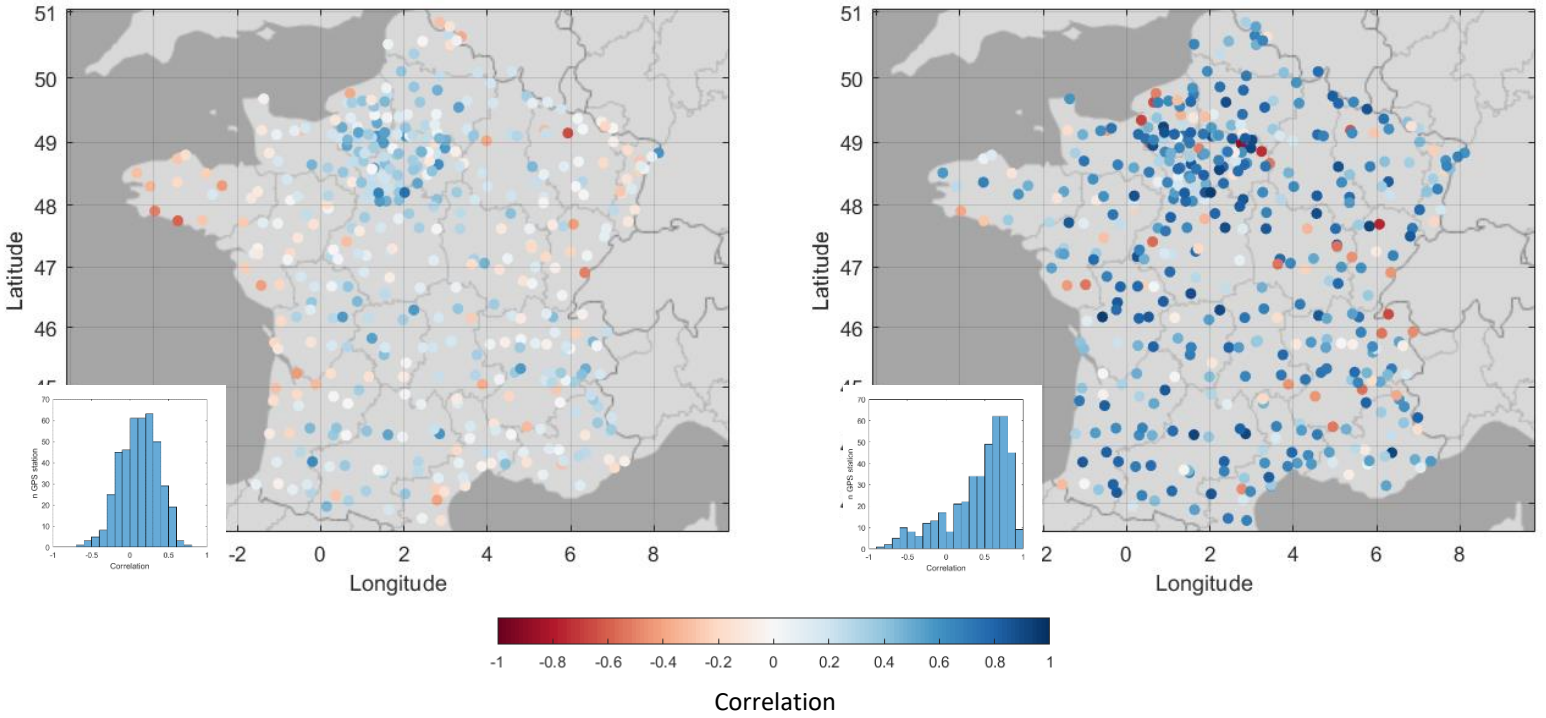


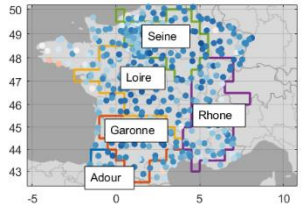
GPS displacement and modelled displacement from in-situ groundwater at GPS sites

$disp_{GW\_GPS}$ vs $disp_{GW\_borehole}$: correlation

Using surface hydrology variation from WGHM to obtain loading-induced vertical displacement caused by surface water variation,

$$disp_{GW\_GPS} = disp_{GPS} - disp_{WGHM\ surface}$$





Subbasin	full signal	interannual signal	
	Mean Correlation	Mean Correlation	N stations with correlation>0.6 (%)
Adour	0.15	0.64	75%
Garonne	0.14	0.47	45%
Loire	0.15	0.43	45%
Rhone	0.09	0.30	29%
Seine	0.26	0.47	51%
All France	0.12	0.41	42%

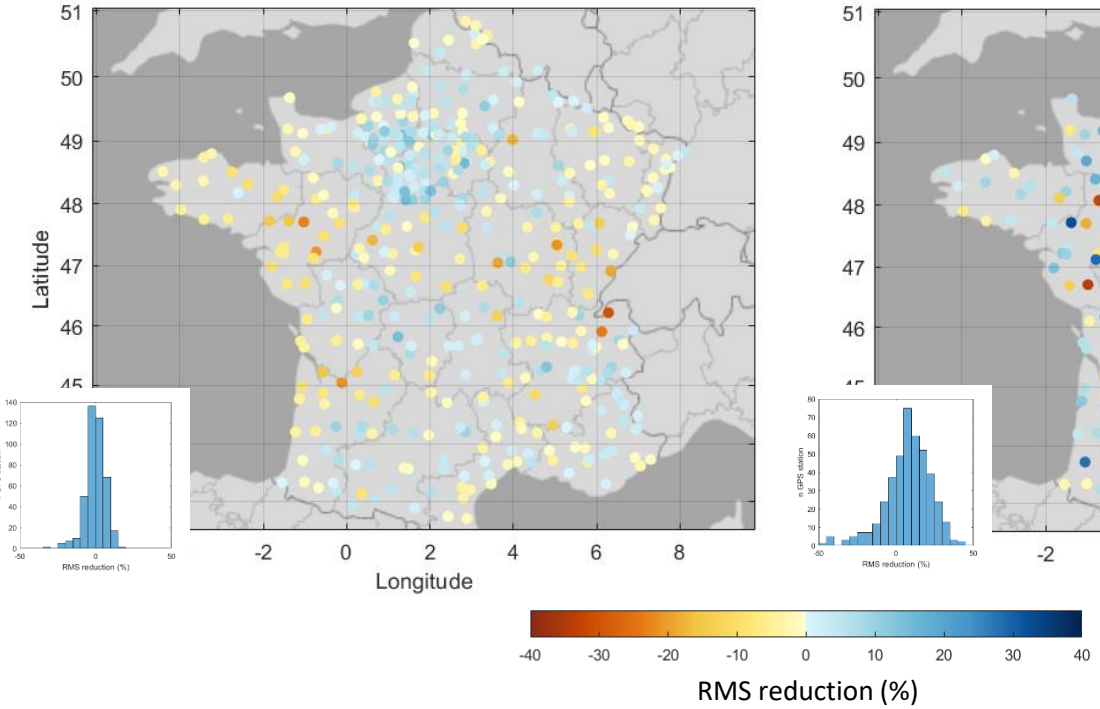
$disp_{GW\_GPS}$ vs $disp_{GW\_borehole}$ has better correlation for the interannual than full signal

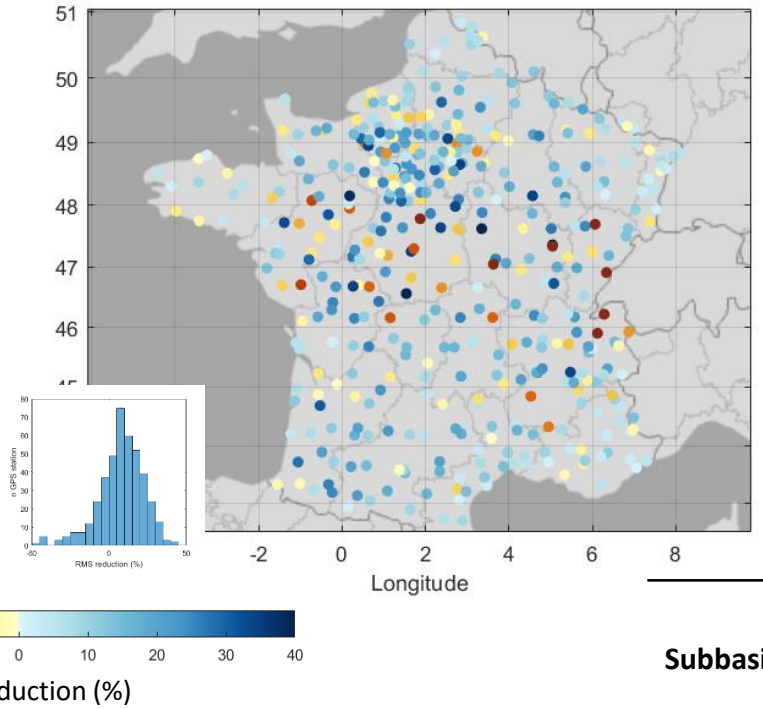
→ Needs further analysis related to the seasonal variabilities

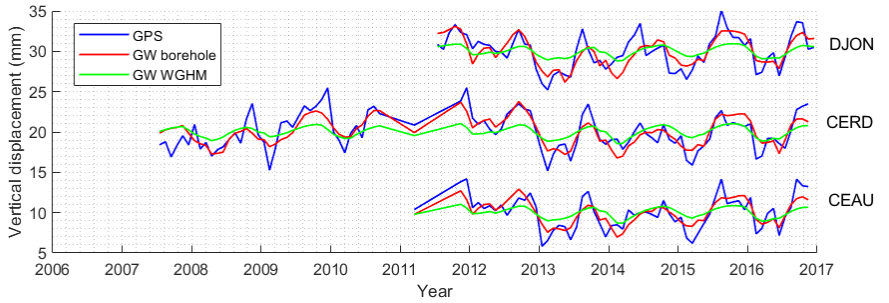
$disp_{GW\_GPS}$ vs $disp_{GW\_borehole}$: RMS reduction

Using surface hydrology variation from WGHM to obtain loading-induced vertical displacement caused by surface water variation,

$$disp_{GW\_GPS} = disp_{GPS} - disp_{WGHM\ surface}$$



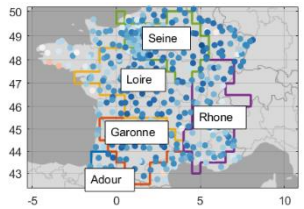




The EWH from in-situ data has larger amplitudes than WGHM. Possible reason is due to the use of global porosity GLHYMPS (Gleeson et al, 2014) to convert from level to storage

Use scaled $disp_{GW\_borehole}$ for RMS reduction evaluation

$disp_{GW\_GPS}$ vs $disp_{GW\_borehole}$ has better fit for the interannual than full signal



Subbasin	full signal		interannual signal	
	Mean RMS reduction (%)	N syations positive RMS reduction (%)	Mean RMS reduction (%)	N stations positive RMS reduction (%)
Adour	16.99	38%	17.28	88%
Garonne	14.05	50%	9.74	74%
Loire	10.76	48%	7.67	67%
Rhone	6.63	38%	0.41	73%
Seine	12.32	67%	10.83	77%
All France	9.88	45%	7.11	75%

Summary and outlook

- We presented preliminary results of the relation between surface deformation observed by GPS and in-situ groundwater in France
- Deformations observed by GPS sites in France are **dominated by elastic deformation** and can be **explained by the variability of in-situ groundwater changes**
- Further studies are needed to infer the relations in various temporal (e.g. annual and semi-annual) and spatial variations

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anita.saraswati@uni.lu

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