وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture
Kingdom of Saudi Arabia المملكة العربية السعودية

Monitoring continental water storage with GNSS and GRACE observations

منتدى المياه السعودي
saudi water forum SWF 2021
استدامة المياه والمسؤولية العالمية

Stacy Larochelle & Jean-Philippe Avouac
California Institute of Technology
In collaboration with Kristel Chanard, Adriano Gualandi, Luce Fleitout, Jérome Fortin, Paul Rebischung, Sophie Violette & Center of Excellence for Earth and Space Science at KACST

7-9 فبراير 2021 • فندق هيلتون الرياض - غرناطة

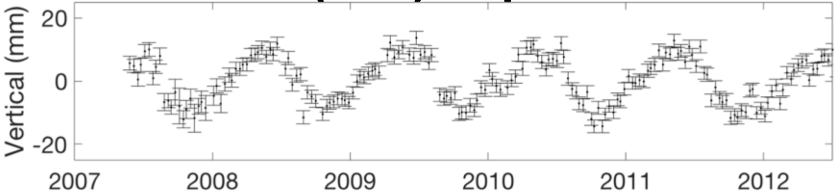
المستشار الفني

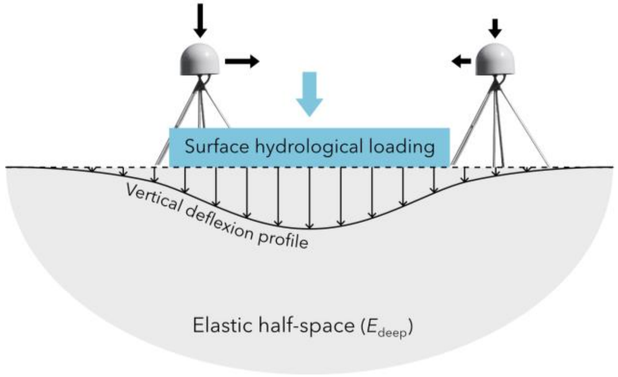
تنفيذ

شركاء التنظيم

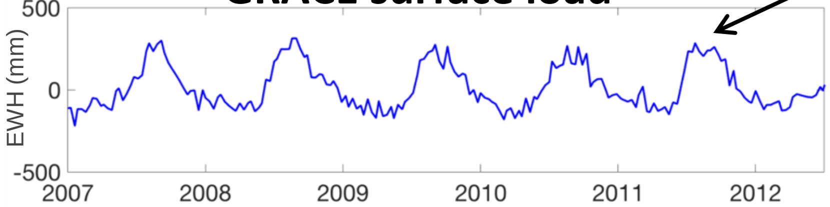
Geodesy records crustal deformation induced by **hydrological processes**

GNSS (GPS) displacement

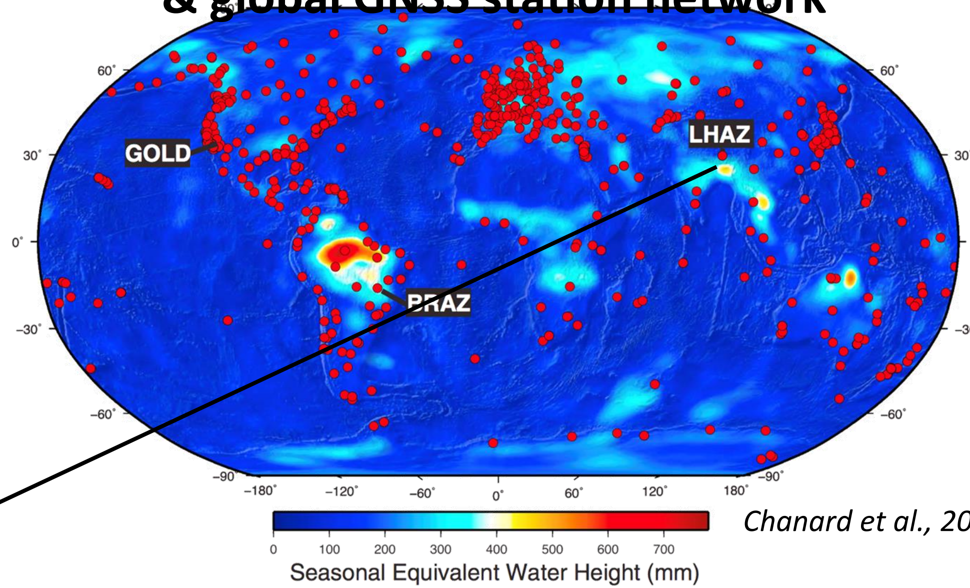




GRACE surface load



GRACE seasonal peak-to-peak amplitudes & global GNSS station network



Chanard et al., 2018

GNSS datasets contain **many sources** of seasonal signals

Hydrology-induced deformation →

← Non-hydrology-induced deformation

- Thermal effects
- Atmospheric pressure
- Tectonic deformation

↑

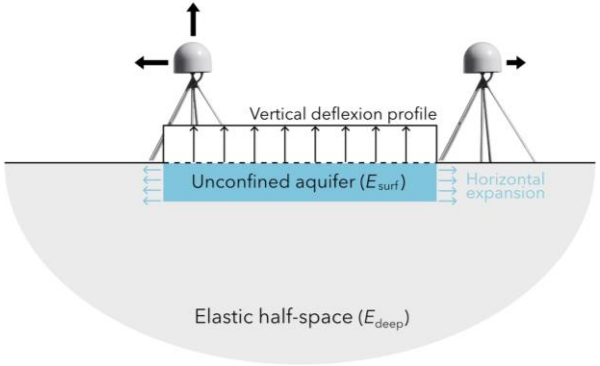
Noise & Systematic Errors

- Draconitic signals
- Aliasing from mismodelled tides
- Environmental effects

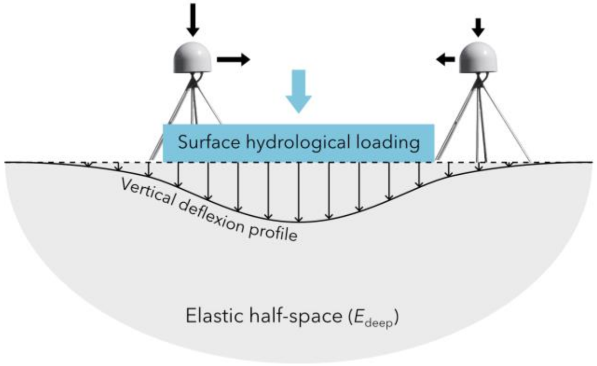
Various sources among hydrology-induced seasonal signals

Hydrology-induced deformation

Groundwater hydrology

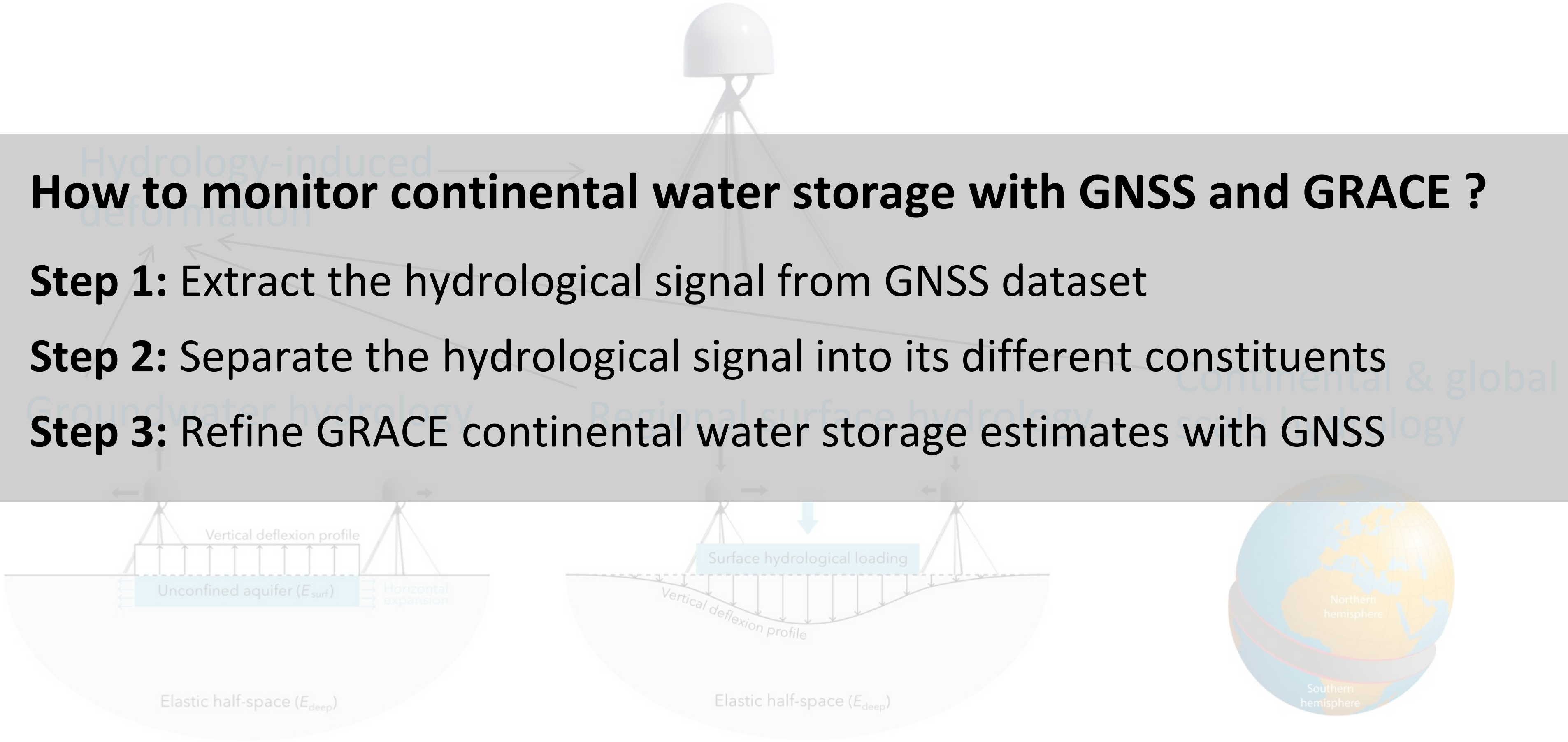


Regional surface hydrology



Continental & global scale hydrology

Various sources among hydrology-induced seasonal signals



How to monitor continental water storage with GNSS and GRACE ?

Step 1: Extract the hydrological signal from GNSS dataset

Step 2: Separate the hydrological signal into its different constituents

Step 3: Refine GRACE continental water storage estimates with GNSS

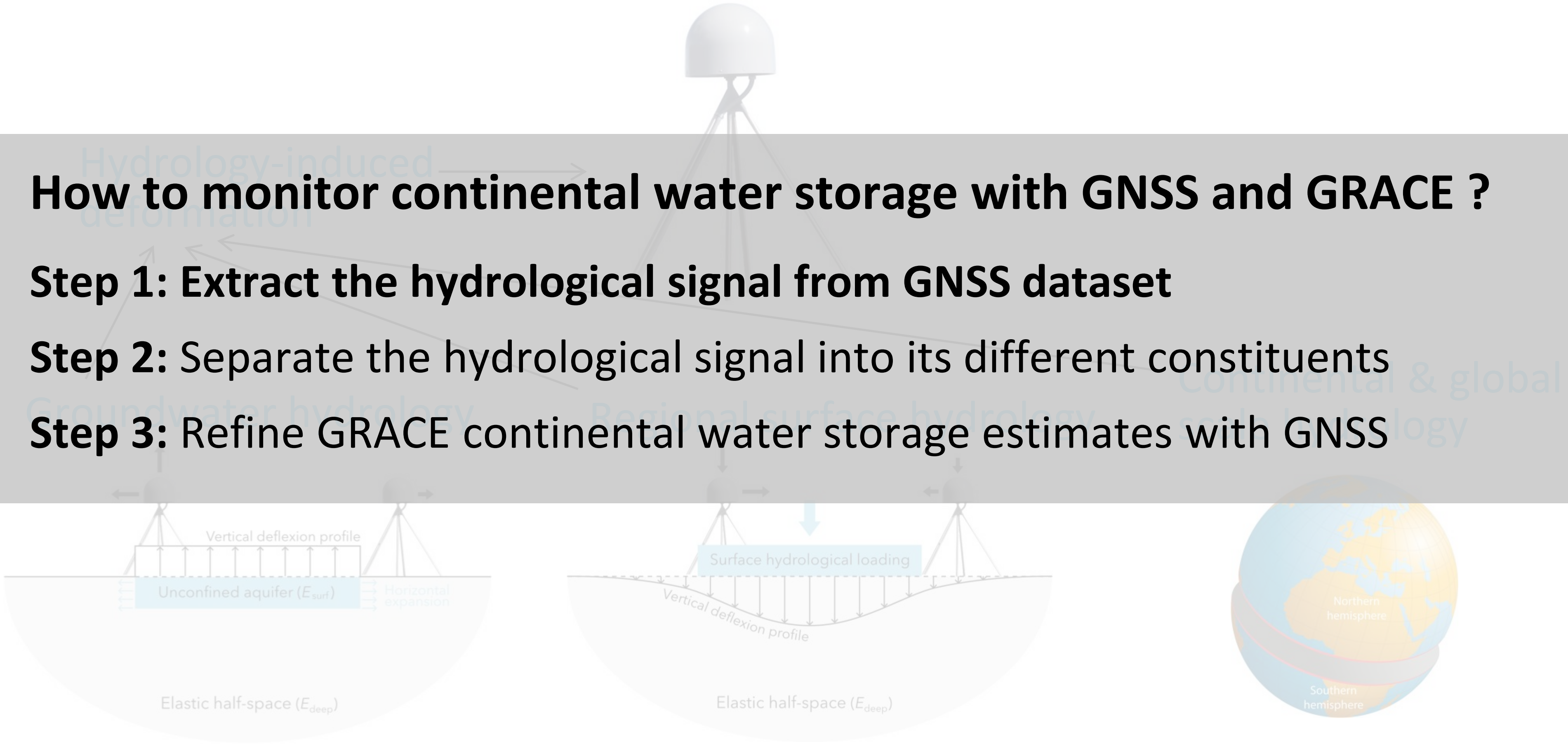
Various sources among hydrology-induced seasonal signals

How to monitor continental water storage with GNSS and GRACE ?

Step 1: Extract the hydrological signal from GNSS dataset

Step 2: Separate the hydrological signal into its different constituents

Step 3: Refine GRACE continental water storage estimates with GNSS



Independent Component Analysis (ICA)

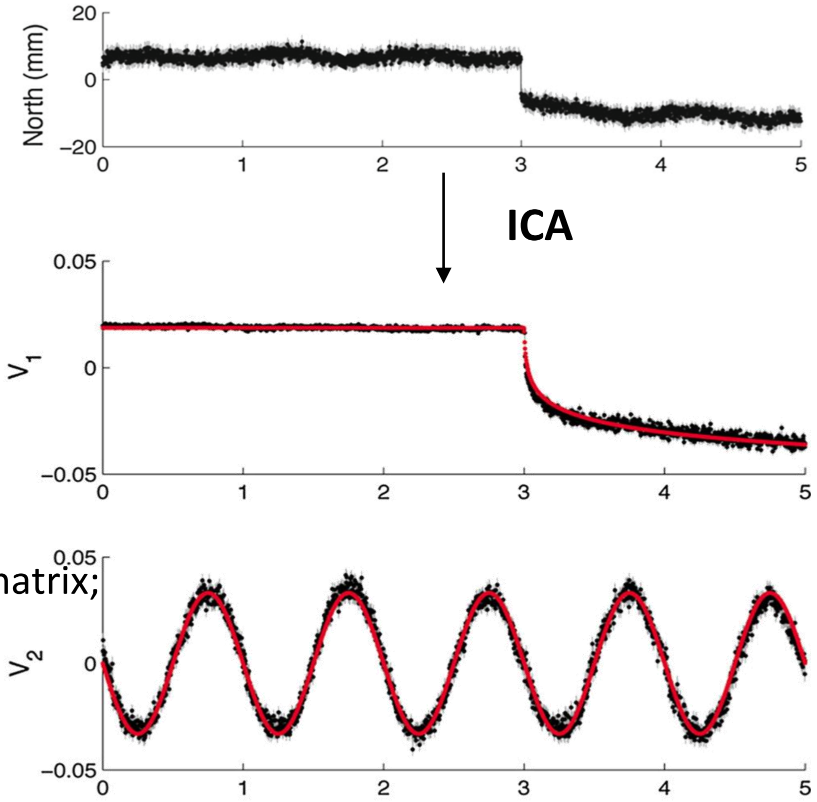
- ICA is a multivariate statistical technique used to decompose a signal into its **independent sources**.

- The sources are characterized in the **space and time domains** as follows:

$$\mathbf{X}_{M\times T} \cong \mathbf{U}_{M\times N}\boldsymbol{S}_{N\times N}\mathbf{V}_{N\times T}^{T}$$

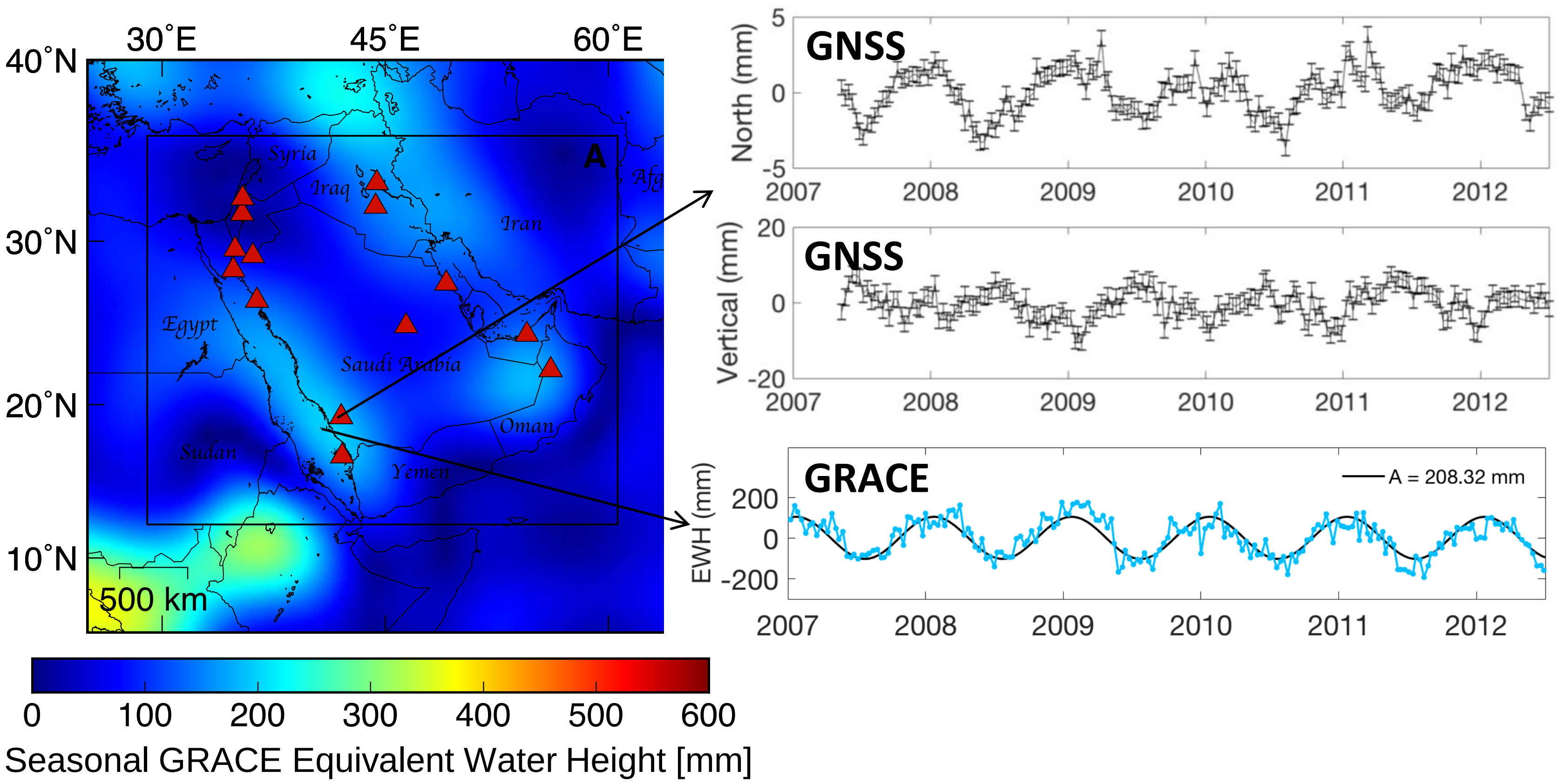
X: data matrix; U: spatial distribution matrix; S: weighing matrix;
V: temporal evolution matrix; M: number of stations;
T: number of epochs; N: number of components (sources)

- ICA extracts the sources purely from the data by maximizing their **statistical independence.**



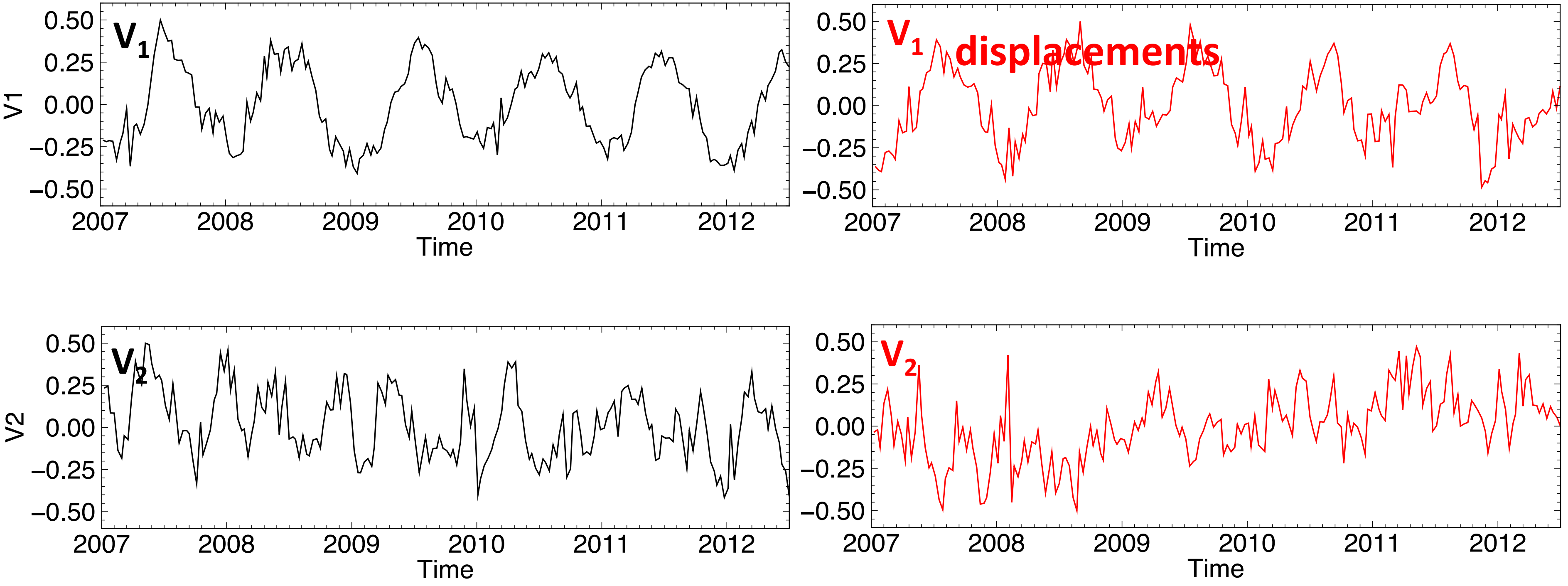
Decomposition of a synthetic GPS time series into its postseismic and seasonal components (*Gualandi et al., 2016*)

Case Study 1: Arabian Peninsula



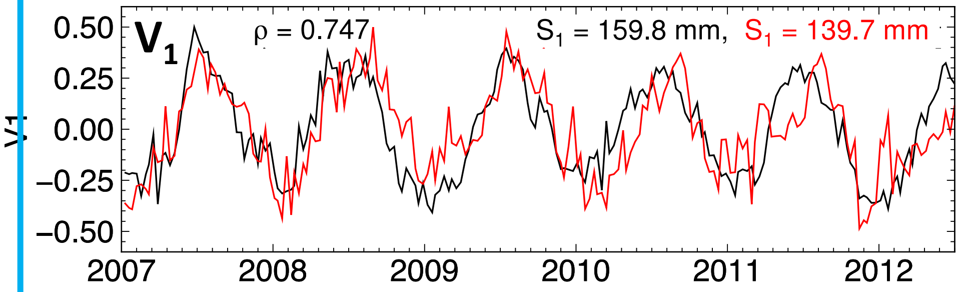
Case Study 1: Perform ICA on GNSS and GRACE model

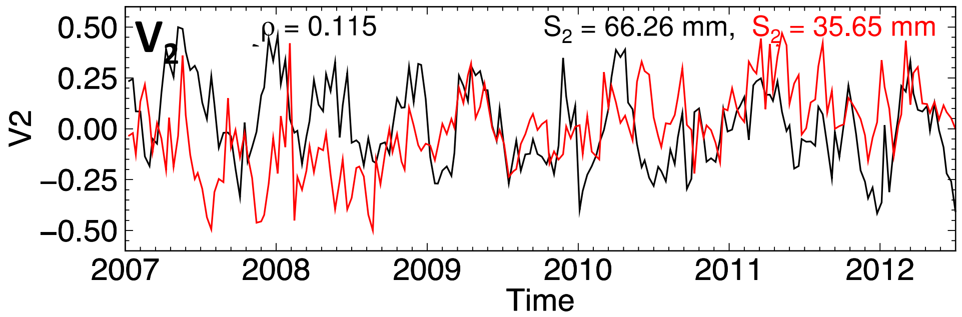
GNSS displacements | **GRACE-derived displacements**



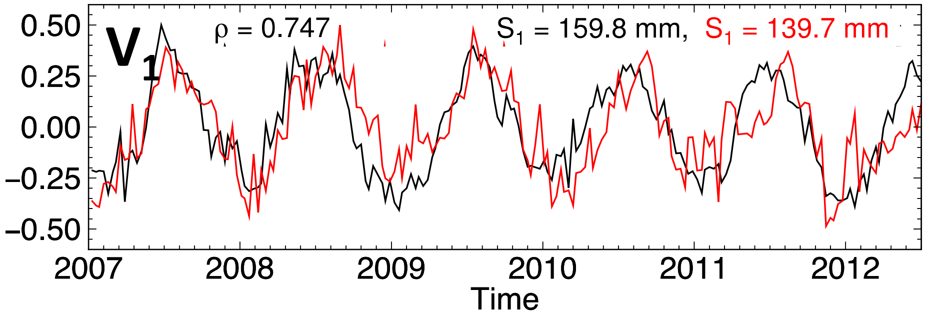
Case Study 1: Identify seasonal hydrological signal

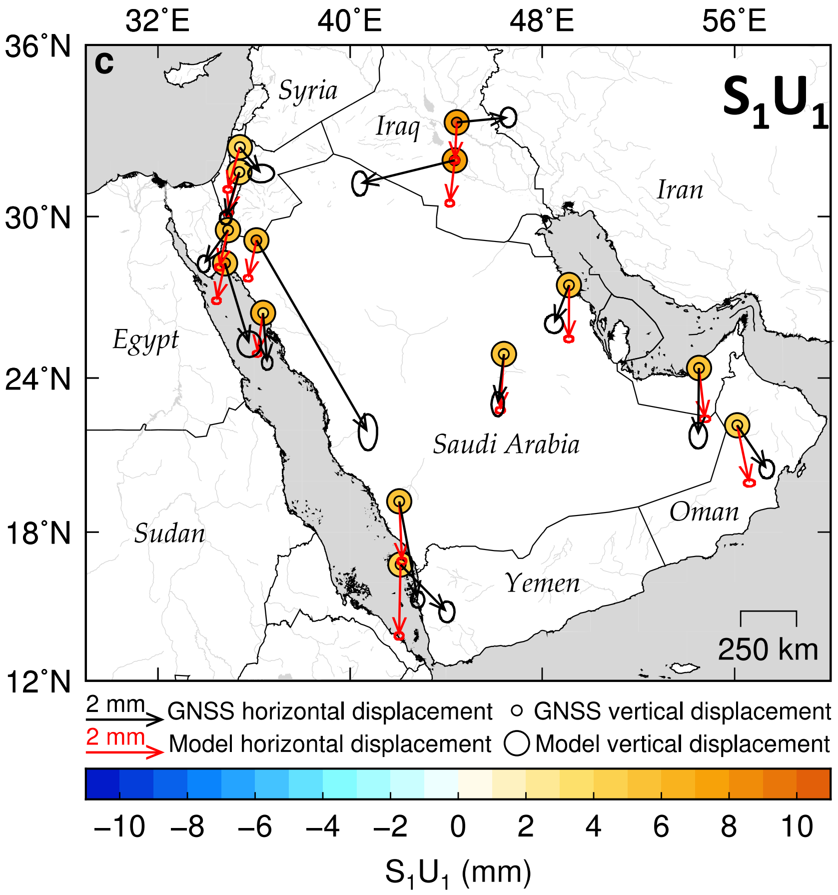
Hydrological Signal





Case Study 1: Spatial distribution of hydrological signal





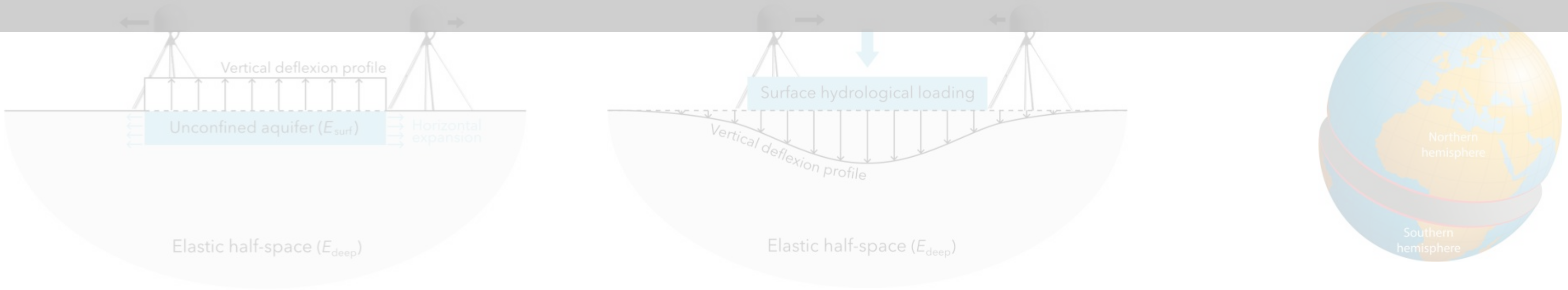
Various sources among hydrology-induced seasonal signals

How to monitor continental water storage with GNSS and GRACE ?

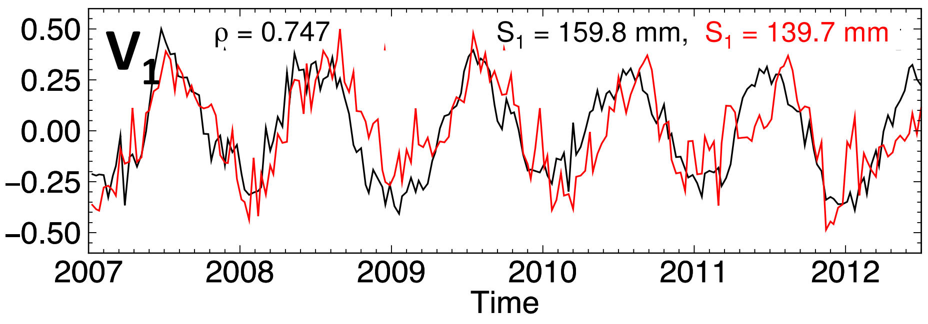
Step 1: Extract the hydrological signal from GNSS dataset

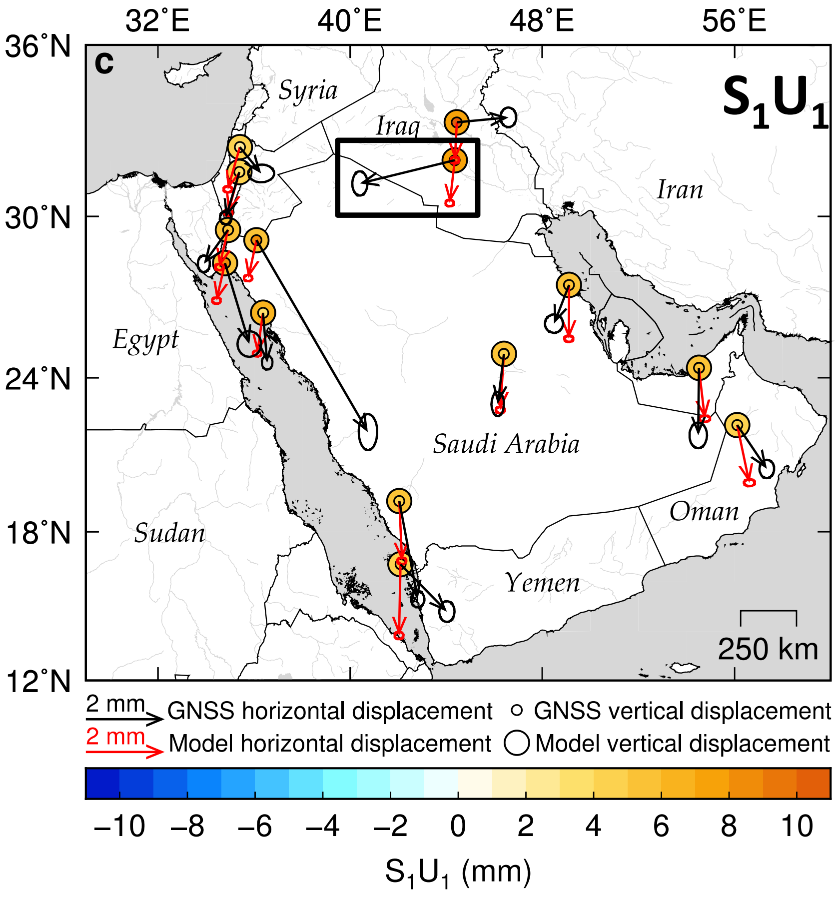
Step 2: Separate the hydrological signal into its different constituents

Step 3: Refine GRACE continental water storage estimates with GNSS

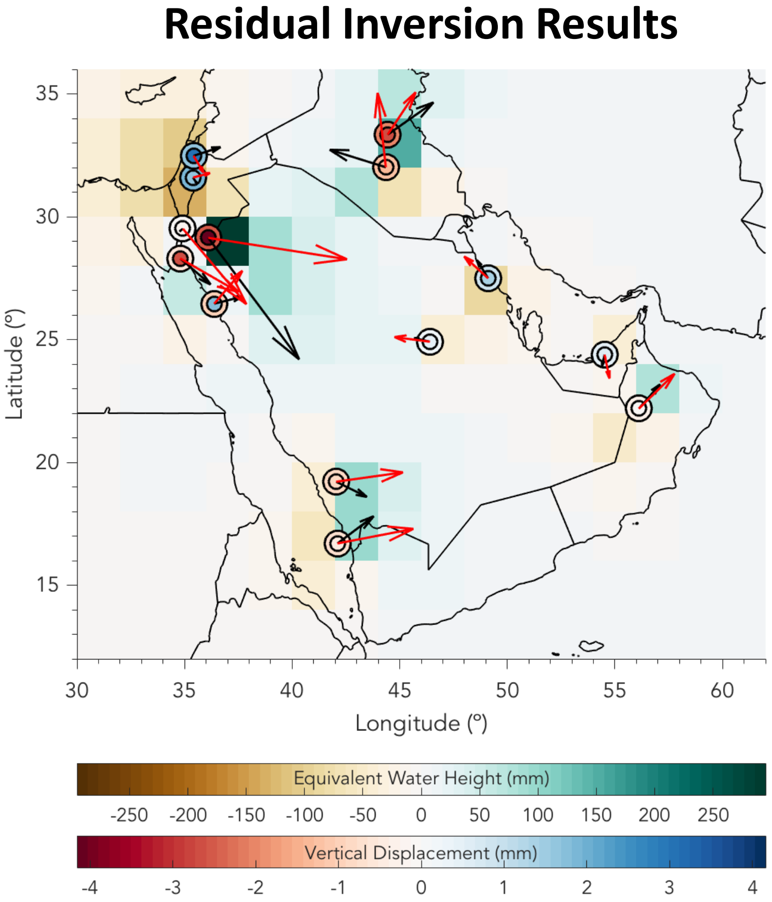


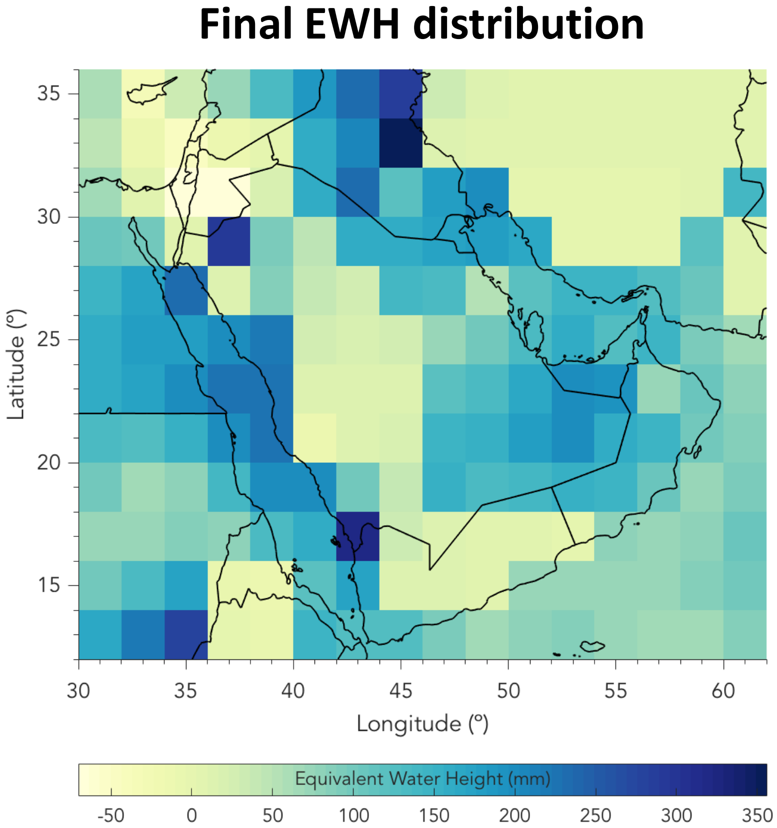
Step 3: Invert GNSS deviations from GRACE model for continental water storage





Step 3: Preliminary inversion results





(with topographic regularization)

Various sources among hydrology-induced seasonal signals

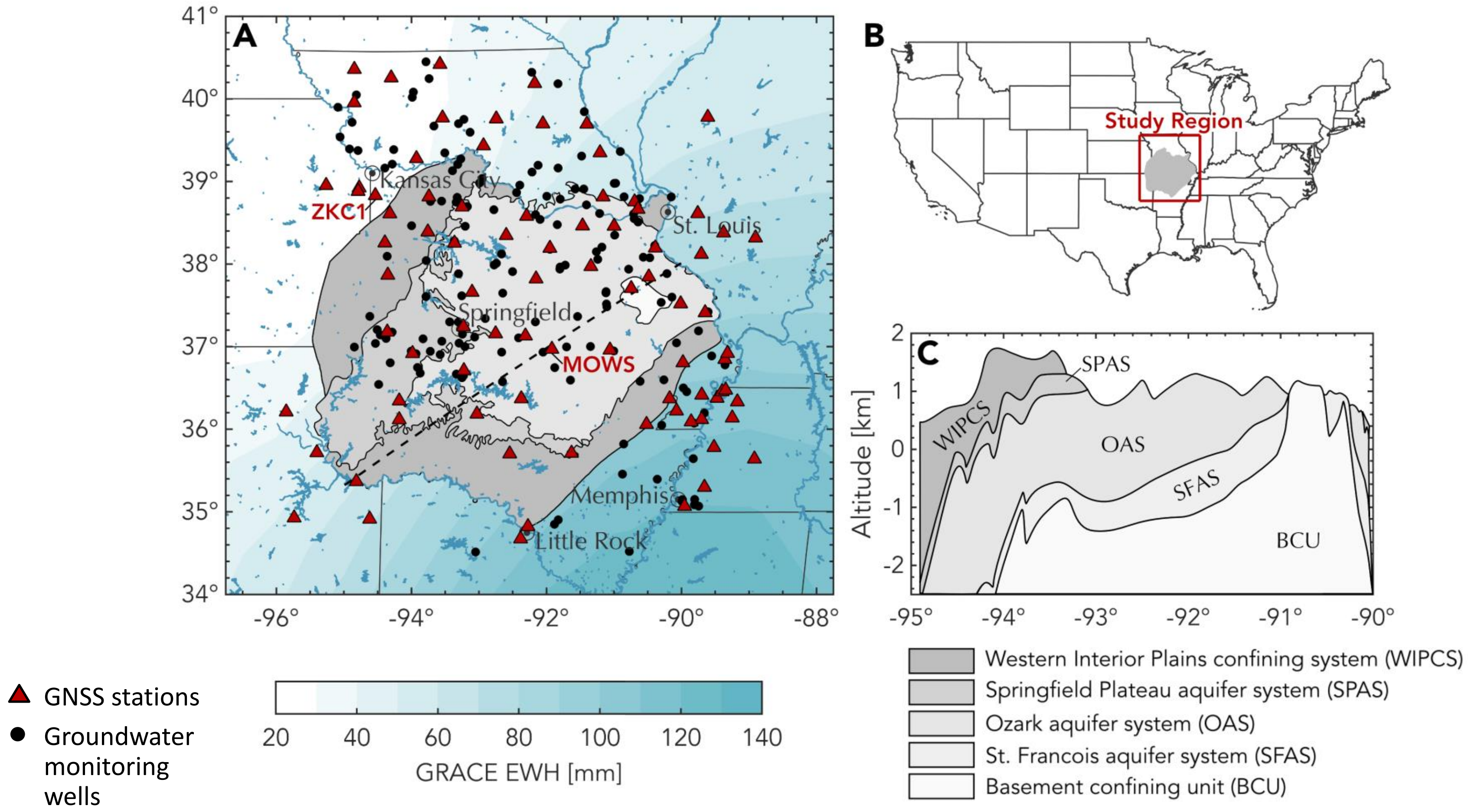
How to monitor continental water storage with GNSS and GRACE ?

Step 1: Extract the hydrological signal from GNSS dataset

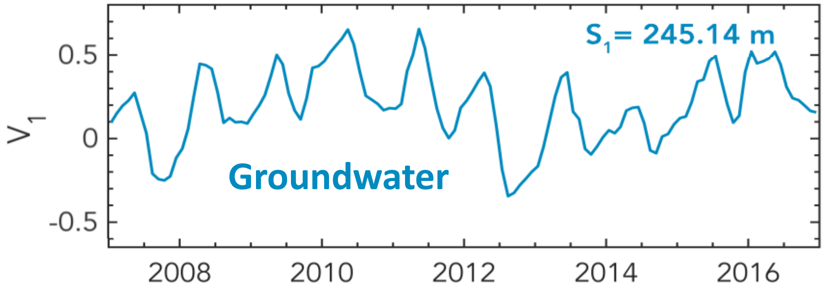
Step 2: Separate the hydrological signal into its different constituents

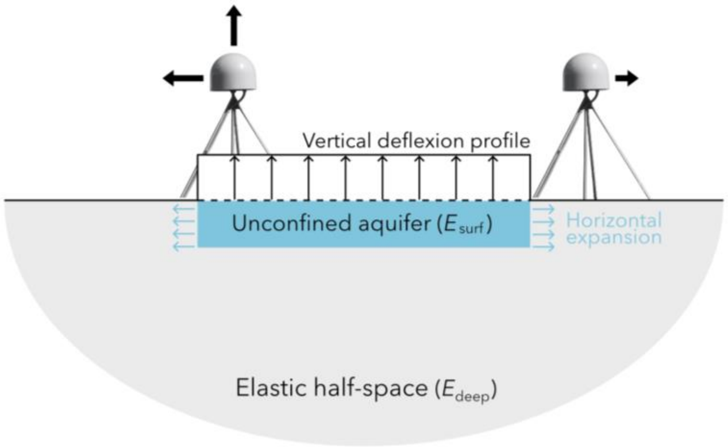
Step 3: Refine GRACE continental water storage estimates with GNSS

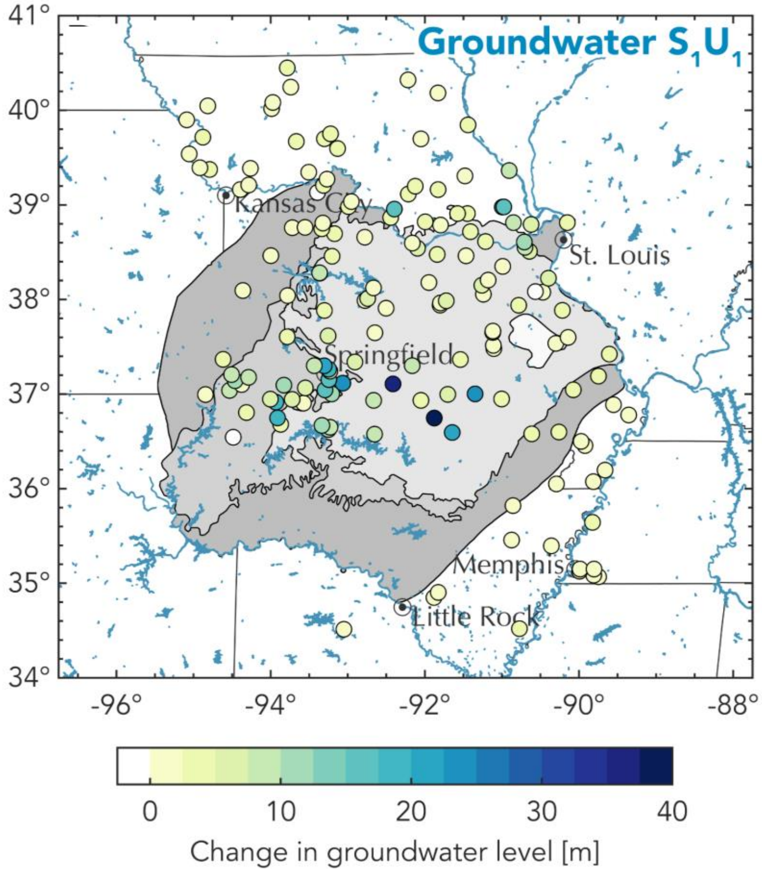
Case Study 2: Ozark Plateaus Aquifer System in Central United States



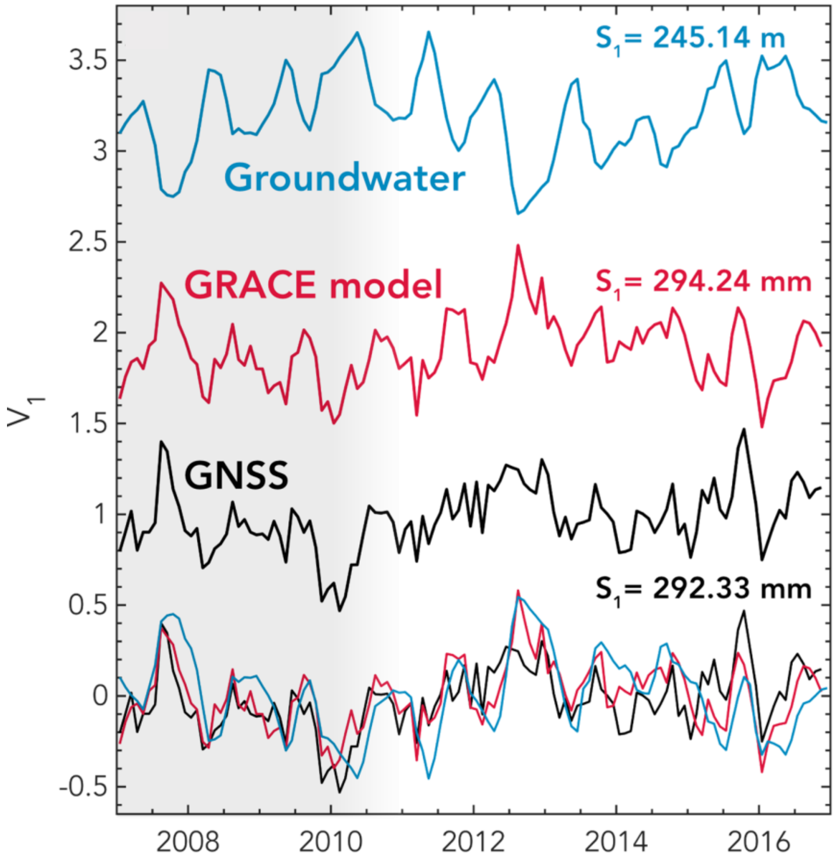
Case Study 2: Perform an ICA on the groundwater dataset

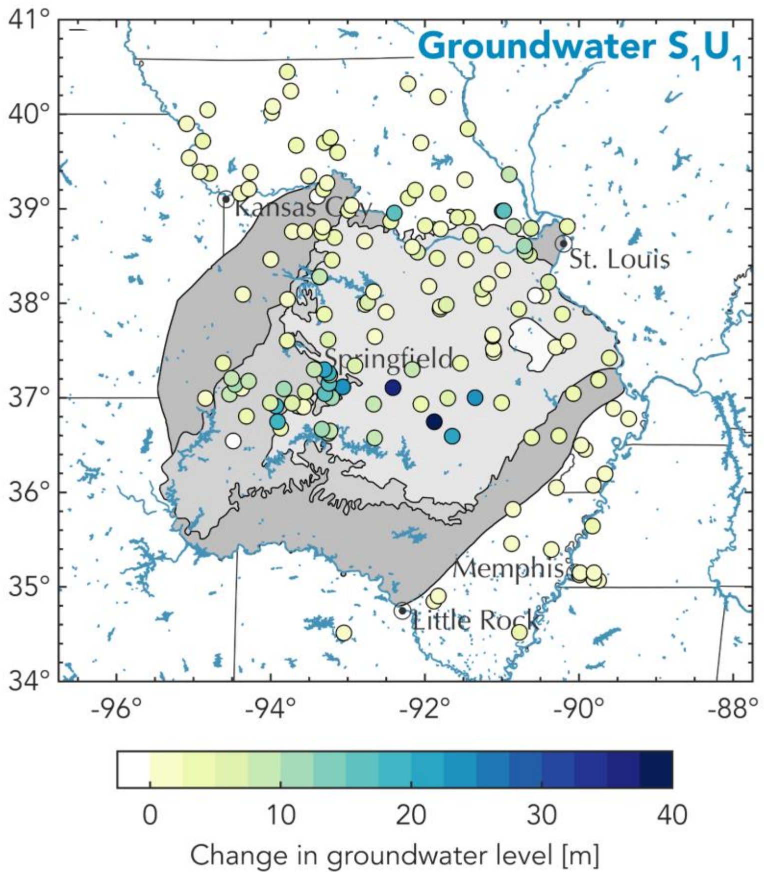






Case Study 2: Compare the first IC across datasets





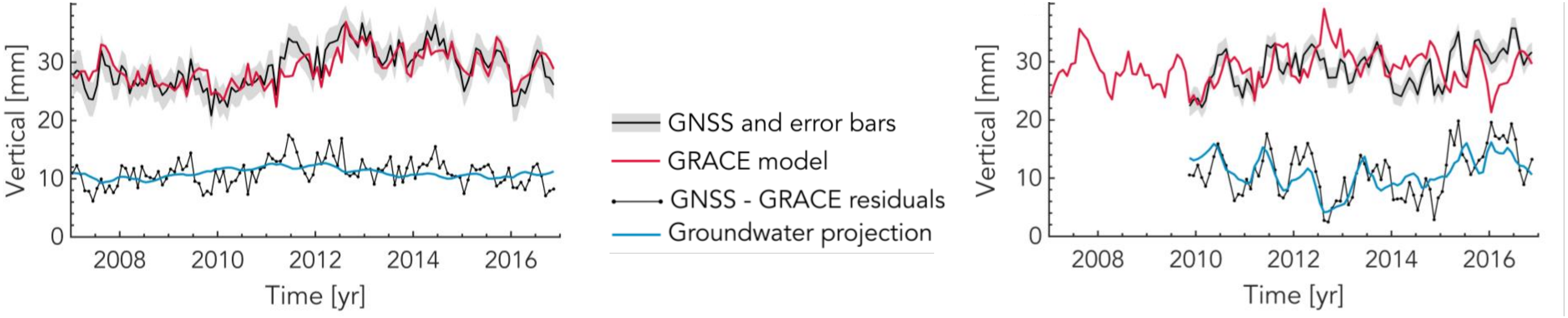
Case Study 2: Extract the groundwater-induced vertical deformation signal

Station ZKC1

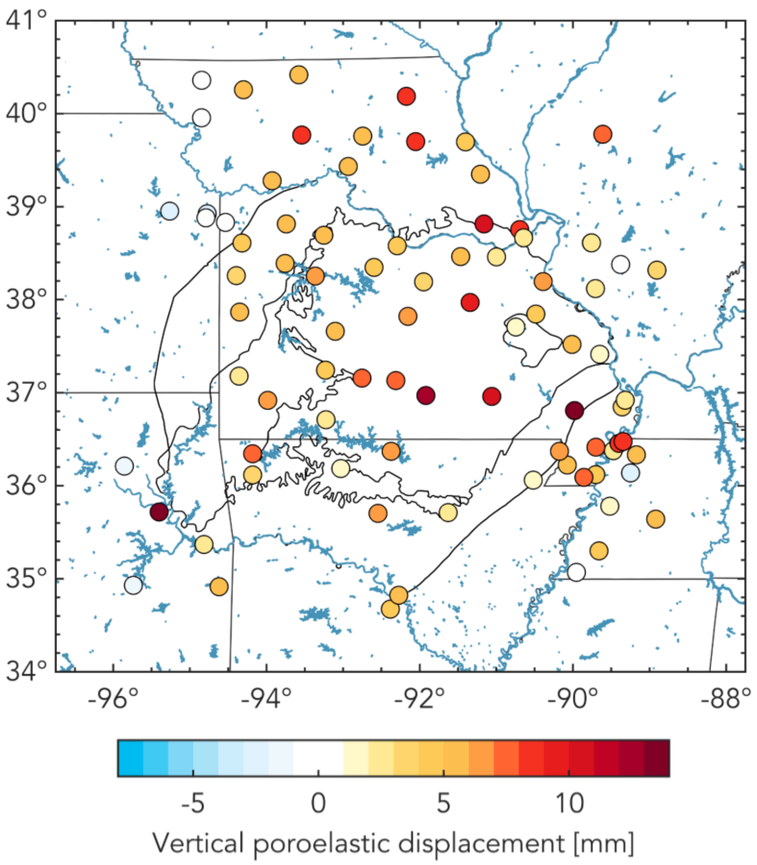
Small vertical groundwater-induced deformation

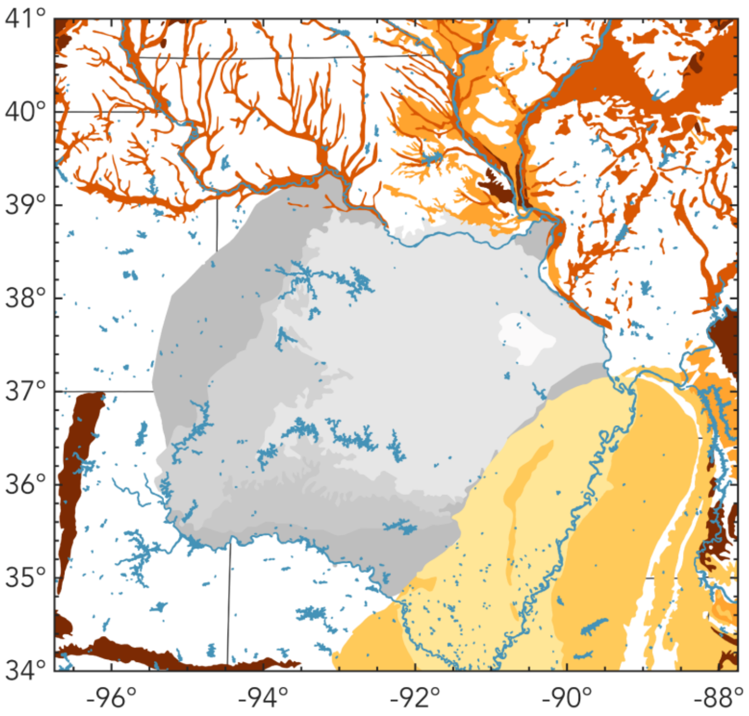
Station MOWS

Large vertical groundwater-induced deformation



Case Study 2: Extract the groundwater-induced vertical deformation signal





The Ozark Plateaus Aquifer System is surrounded by other aquifers

Summary and Conclusions

- We have developed a methodology to extract seasonal hydrologic signals from GNSS datasets with ICA.
- We are working on isolating the different hydrologic components (e.g., surface water, groundwater, continental and global effects) making up this seasonal signal.
- We are working on an inversion scheme to improve GRACE water storage maps from the isolated surface water and groundwater signals.

Future Work

- Continue developing our methodologies in collaboration with hydrologists and geohydrologists.
- Make use of the denser GNSS network in Saudi Arabia (particularly on top of aquifer systems).

وزارة البيئة والمياه والزراعة
Ministry of Environment Water & Agriculture
Kingdom of Saudi Arabia المملكة العربية السعودية

THANK YOU

منتدى المياه السعودي
saudi water forum SWF 2021
حضوري / افتراضي

استدامة المياه .. مسؤولية الجميع

7-9 فبراير 2021 • فندق هيلتون الرياض - غرناطة / افتراضيًا

المستشار الفني

تنفيذ

شركاء التنظيم