Hydro-gravimetry as a tool to constrain water mass transfer in catchments. Example from the Strengbach Catchment in the Vosges mountains, France.

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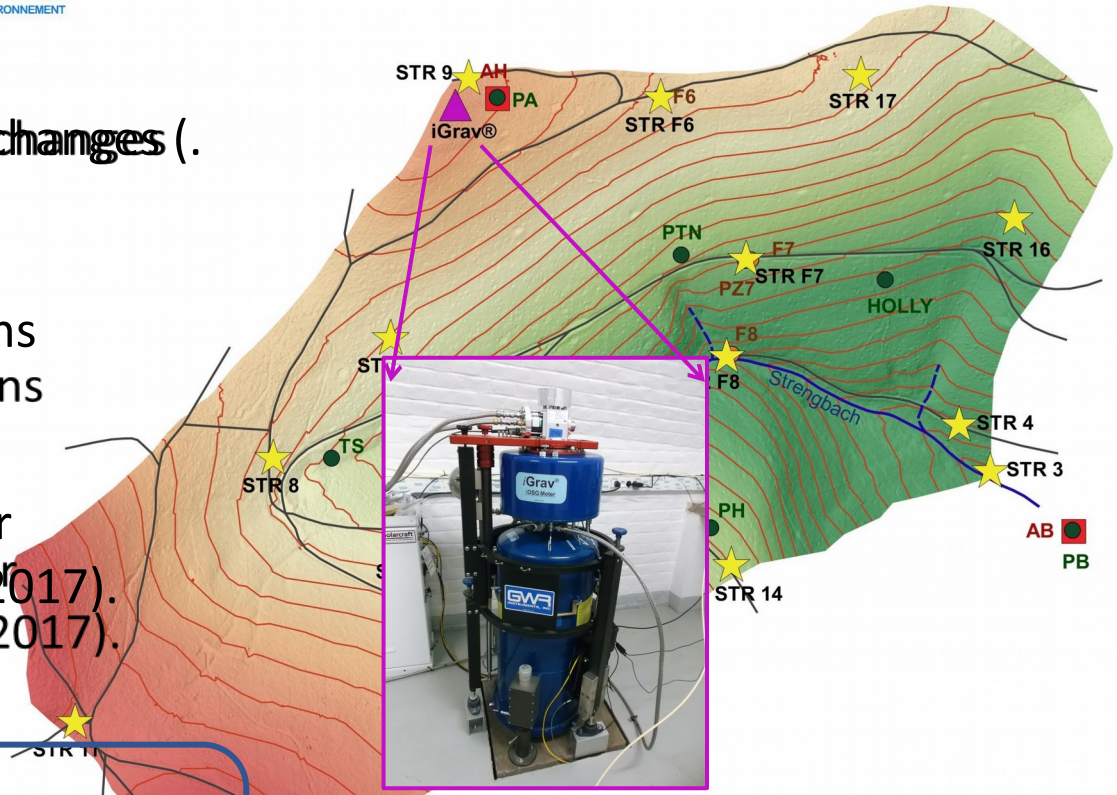
Colloque G2, 12-14 novembre 2018, Montpellier, France.

Why gravimetry is a useful tool to constrain water storage changes in hydro-systems ?

- In situ gravimetry :
  - Gravity directly sensitive to water storage changes (. $(10\ \text{cm water} \sim 4{,}2\ \mu gal\ for\ flat\ zones)$.
- Remote-sensing gravimetry (GRACE) :
  - Constrain large hydrological signal variations
- In situ gravimetry :
  - Calibration of local hydrological models for **flat zones** (Hector et al, 2015; Fores et al, 2017).

This study:
In situ iGrav® gravity monitoring ($10^{-2}\mu gal = 10^{-11}\ g$) applied on a **mountainous zone**.

Equipments for the meteorological, hydrological and hybrid gravimetry monitoring



Super-conducting gravimeter iG30

Why gravimetry is a useful tool to constrain water storage changes in hydro-systems ?

- Challenging for strong topographic zones.
- Especially for low seasonal hydrological variations.
- Also very few studies address this topic.

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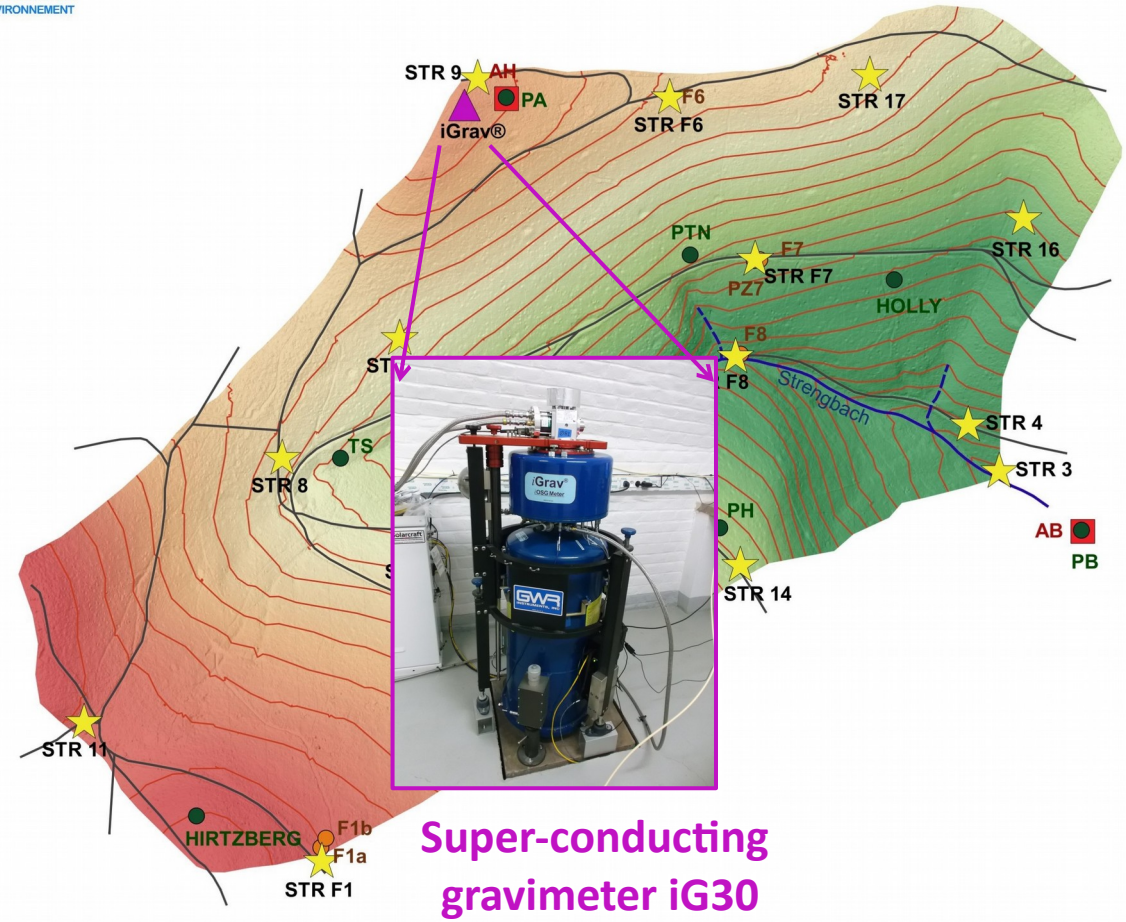
Equipments for the meteorological, hydrological and hybrid gravimetry monitoring

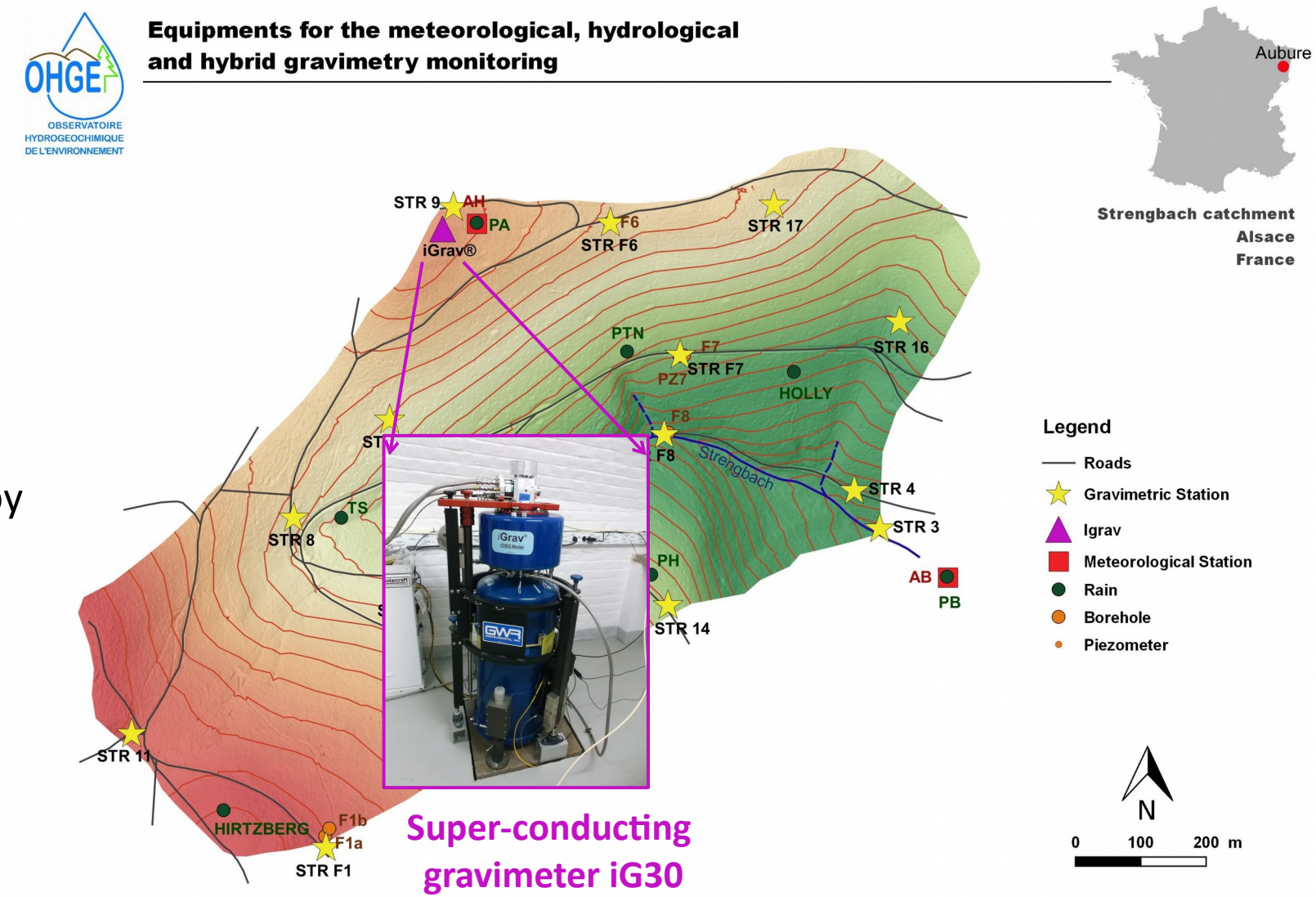


Super-conducting gravimeter iG30

Application to the Strengbach catchment

- Mountainous catchment with **strong topography** (800m-1150m)
- Fractured granitic basement covered by a shallow altered zone (activ aquifer).
- Very reactive hydrological system

Equipments for the meteorological, hydrological and hybrid gravimetry monitoring



Objectives of the talk :

- iGrav® processing workflow: from raw data to the gravity hydrological residual signal.

- Compare the gravity hydrological residual signal with a **global** and a **local** hydrological model.

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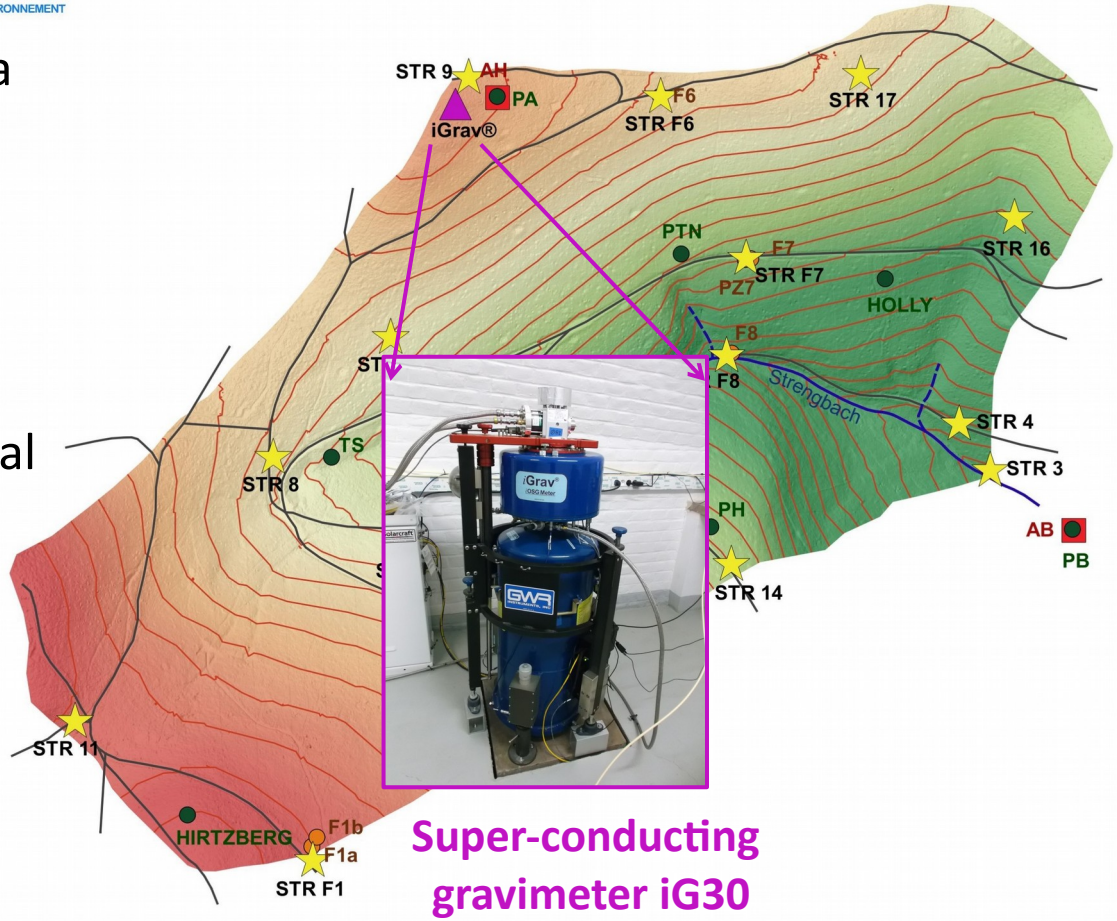
Equipments for the meteorological, hydrological and hybrid gravimetry monitoring



Legend
- Roads
- Gravimetric Station
- Igrav
- Meteorological Station
- Rain
- Borehole
- Piezometer

N
0 100 200 m

Gravity consists in a sum of several geophysical and hydrological signals :

$$g_{raw}(t) = g_{tides} + g_{polar\ motion} + g_{subsidence} + g_{atmospheric\ pressure} + g_{hydrology}$$

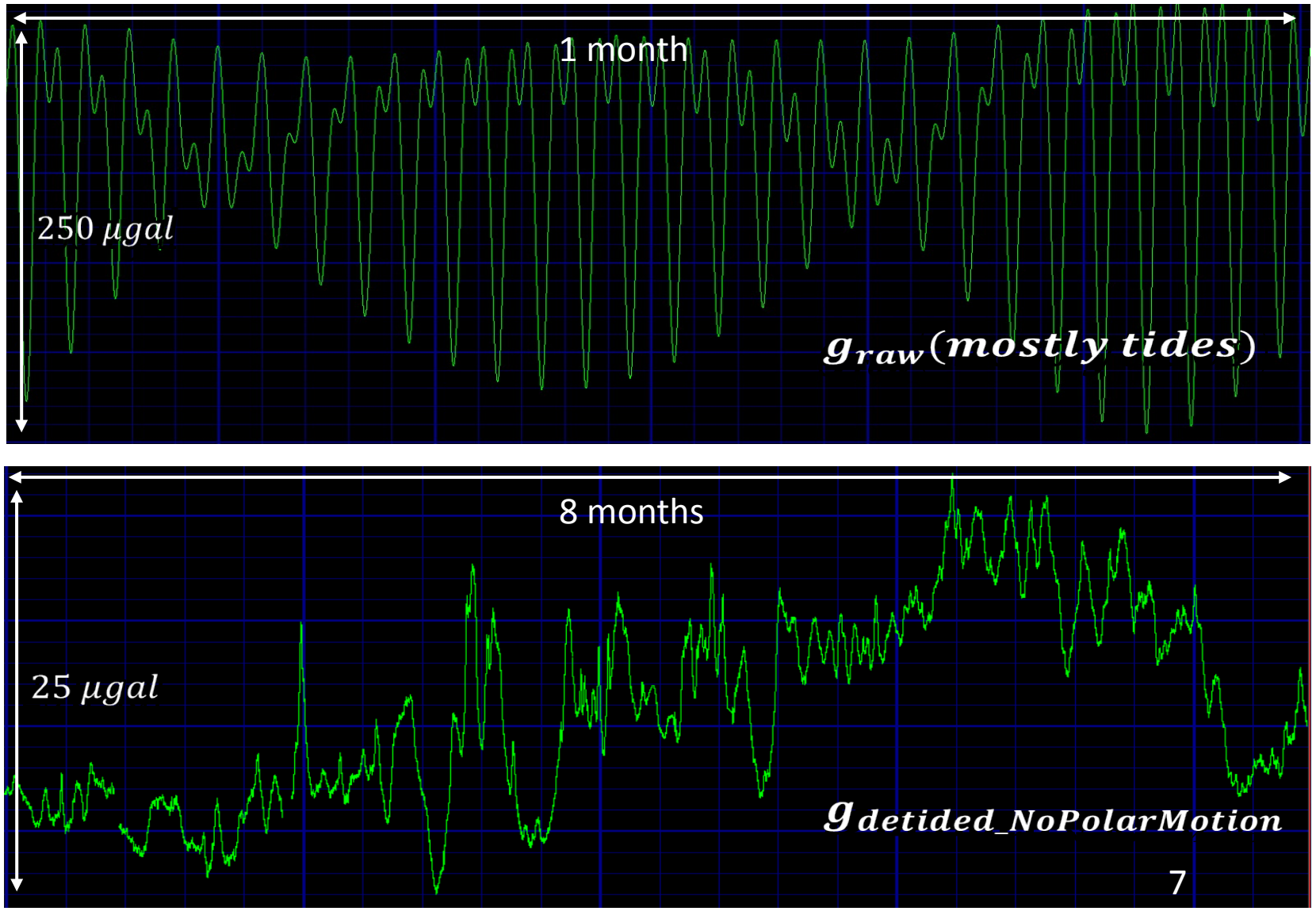
modeled | modeled | negligible | measured | target

- g_{tides} : Due to moving celestial bodies (mainly Moon and Sun).
- $g_{polar\ motion}$: Due to Earth's rotation axis motion.
- $g_{subsidence}$: Due to tectonic subsidence (or uplift).
- $g_{atmospheric\ pressure}$: Gravity effect due to atmospheric pressure fluctuations.
- $g_{hydrology}$: Hydrological signal due to soil water storage changes.

Workflow for iGrav data reduction:

- **Step 1**: Tides and polar motion correction.

→ Reduce amplitude by a factor 10

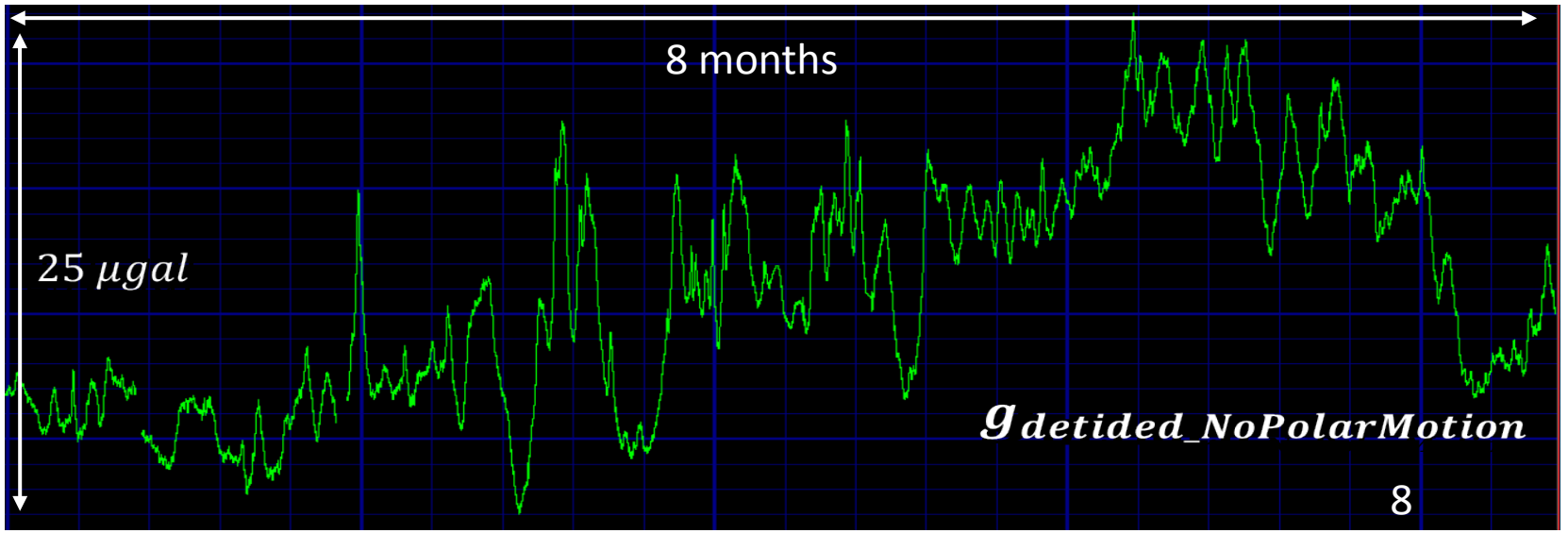


Workflow for iGrav data reduction:

- **Step 2: Pressure effect correction with a barometric admittance:**

$$P_{adm} = -0{,}3\ \mu gal.hPa^{-1}$$

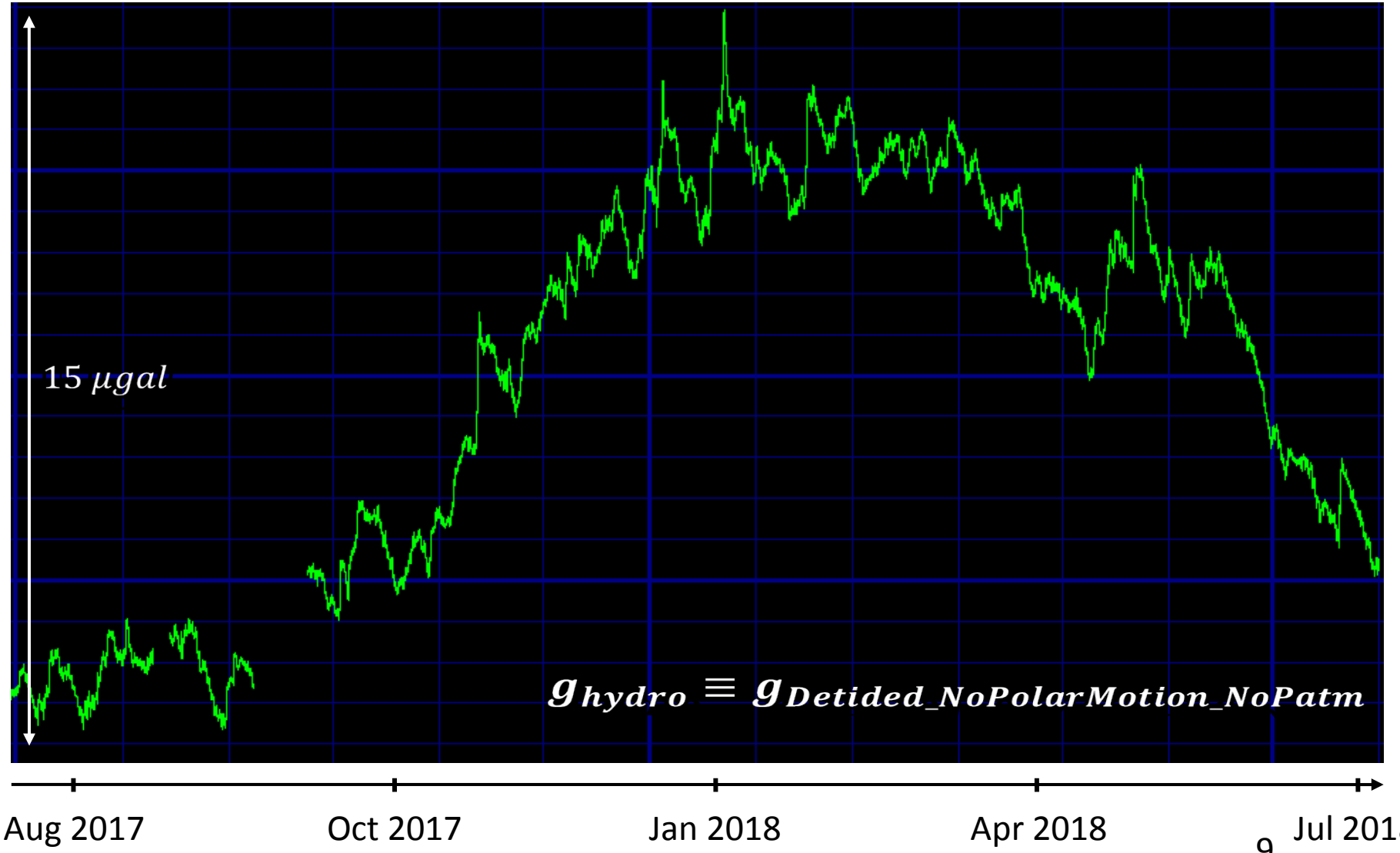
→ Remove the high frequency (daily to weekly) atmospheric signal



Final iGrav hydrological residual:

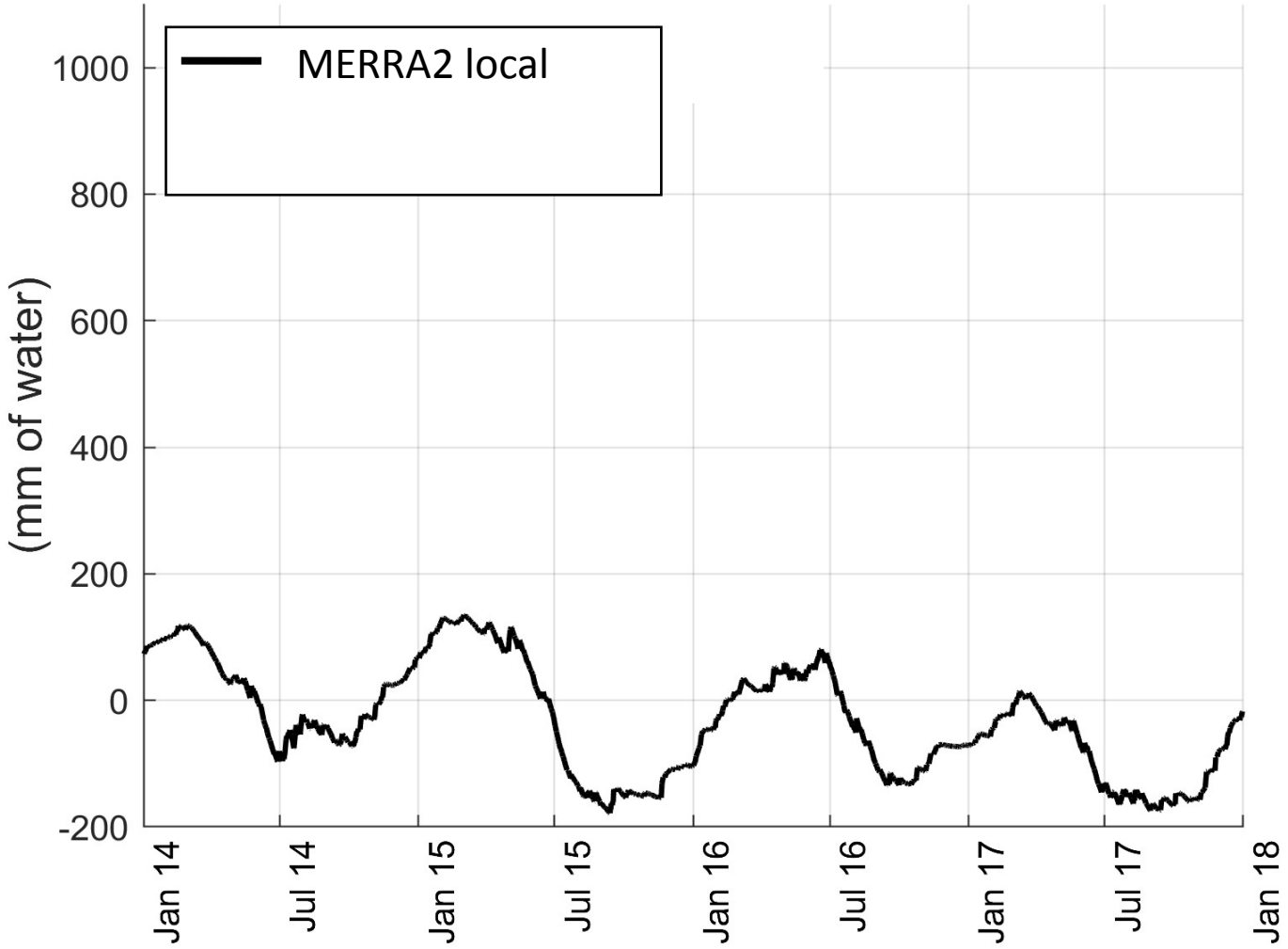
- 1 year of monitoring
- Strong annual cycle
- High frequency content

How well matches the gravity hydrological residual signal to the local and global hydrology ?



Estimation of basin water storage

Choice 1 : Global hydrological model MERRA 2 (~50 km resolution).



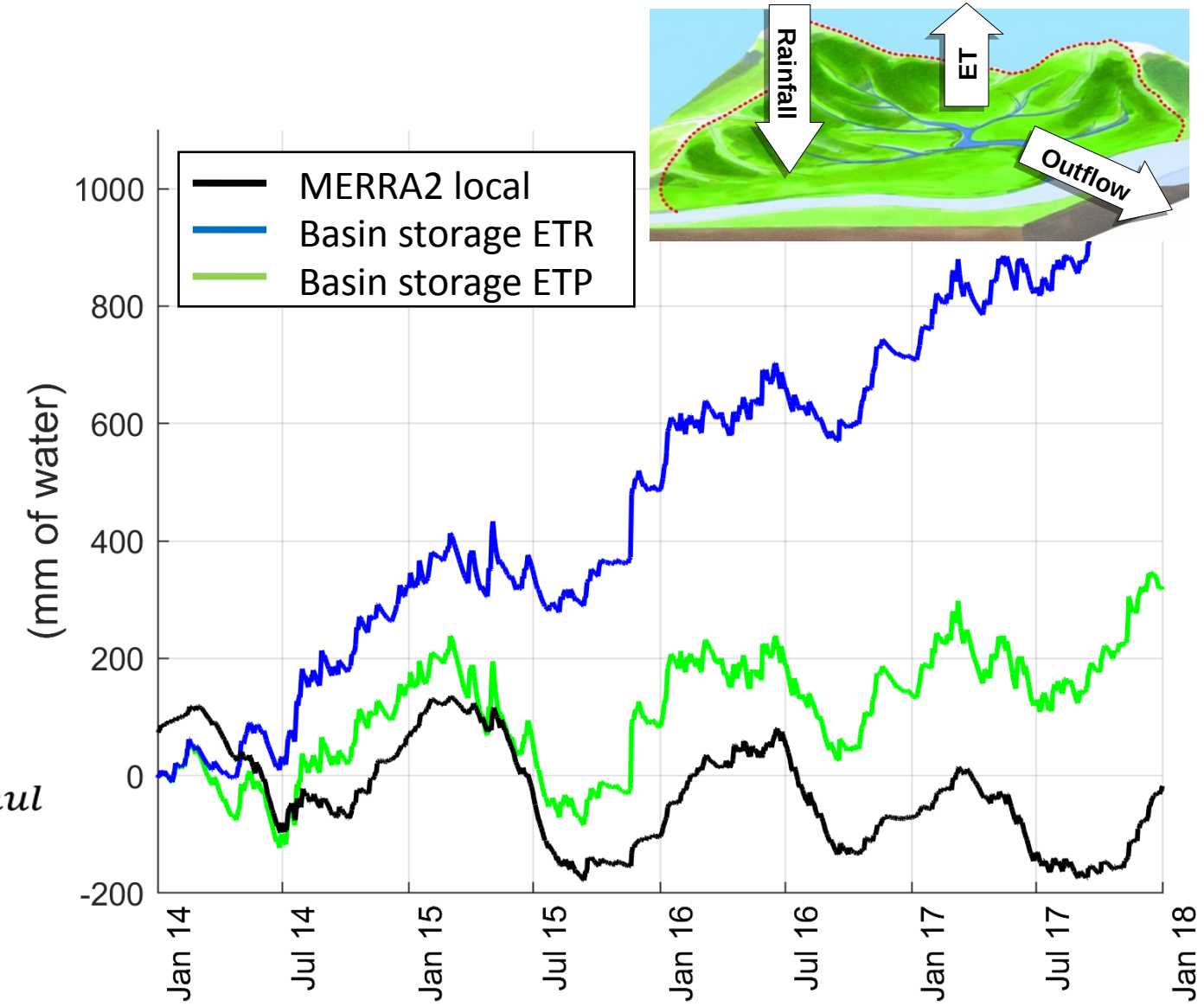
Estimation of basin water storage

Choice 1 : Global hydrological model MERRA 2 (~50 km resolution).

Choice 2 : Local hydrological model using potential ET (ETP) or actual ET (ETR).

$$Storage(t) = Rainfall_{cumul} - Outflow_{cumul} - ET_{cumul}$$

measured measured modeled



Estimation of basin water storage

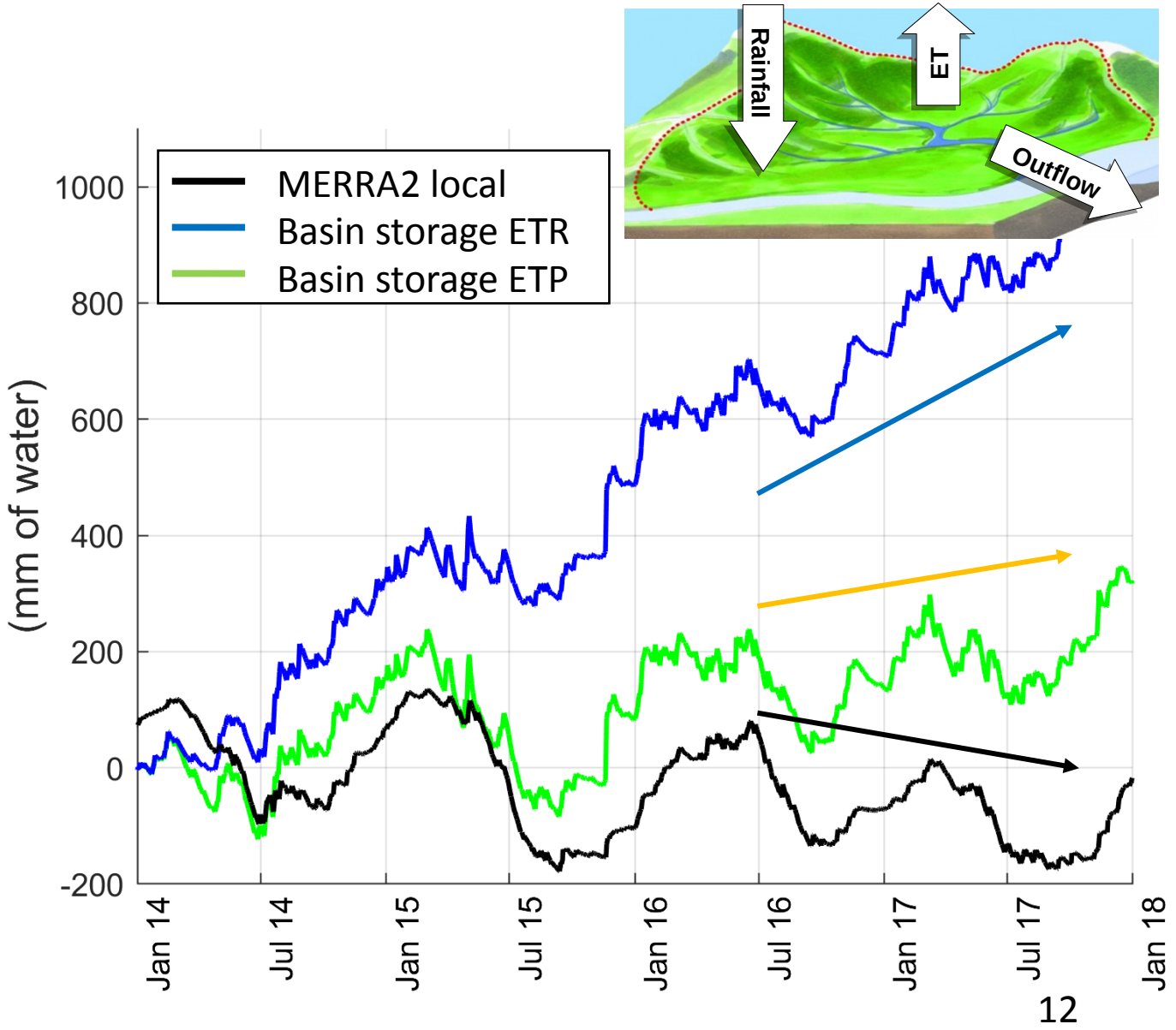
- Global model **MERRA2**:

  Small (non hydrologic ?) negative trend

- Local models **ETR** and **ETP**:

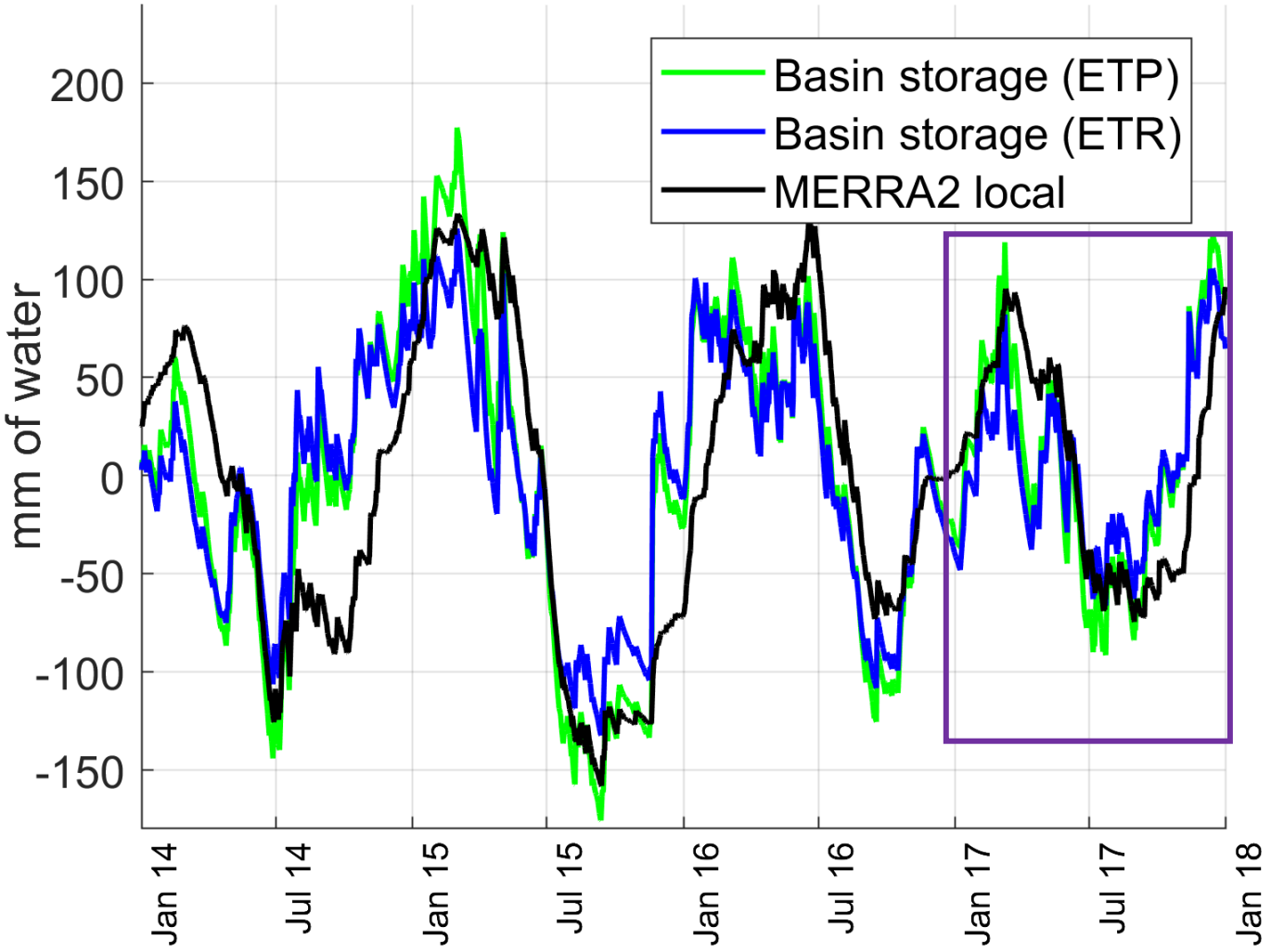
  Strong non hydrologic positive trend

➡ Both global and local models are detrended



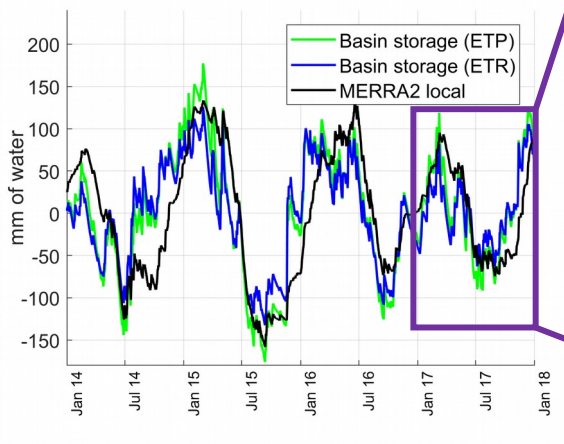
Estimation of basin water storage

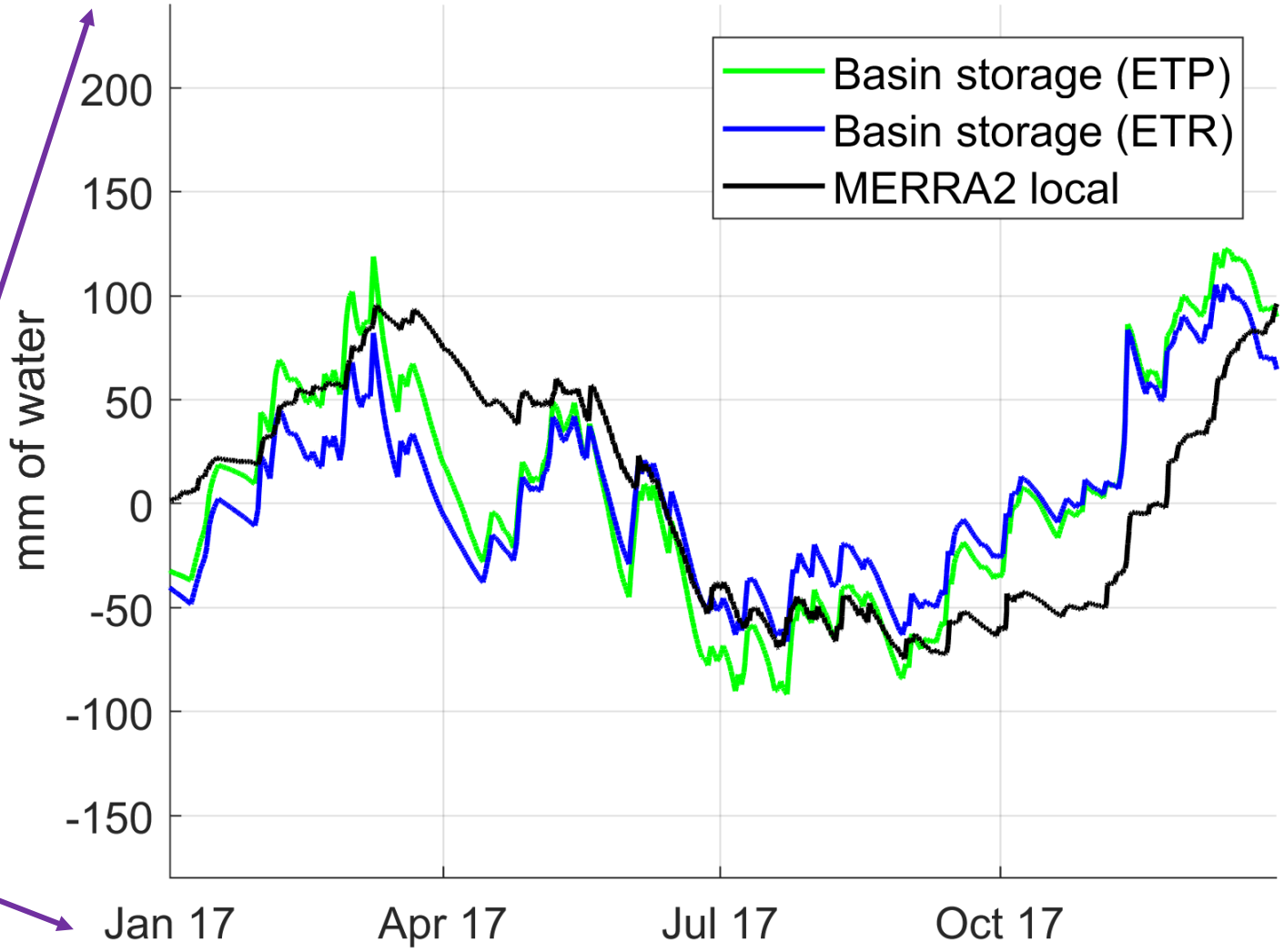
- Local and global hydrological model: similar annual cycle



Estimation of basin water storage

- Local and global hydrological model: similar annual cycle
- Global model MERRA2 is smoother than local hydrological model



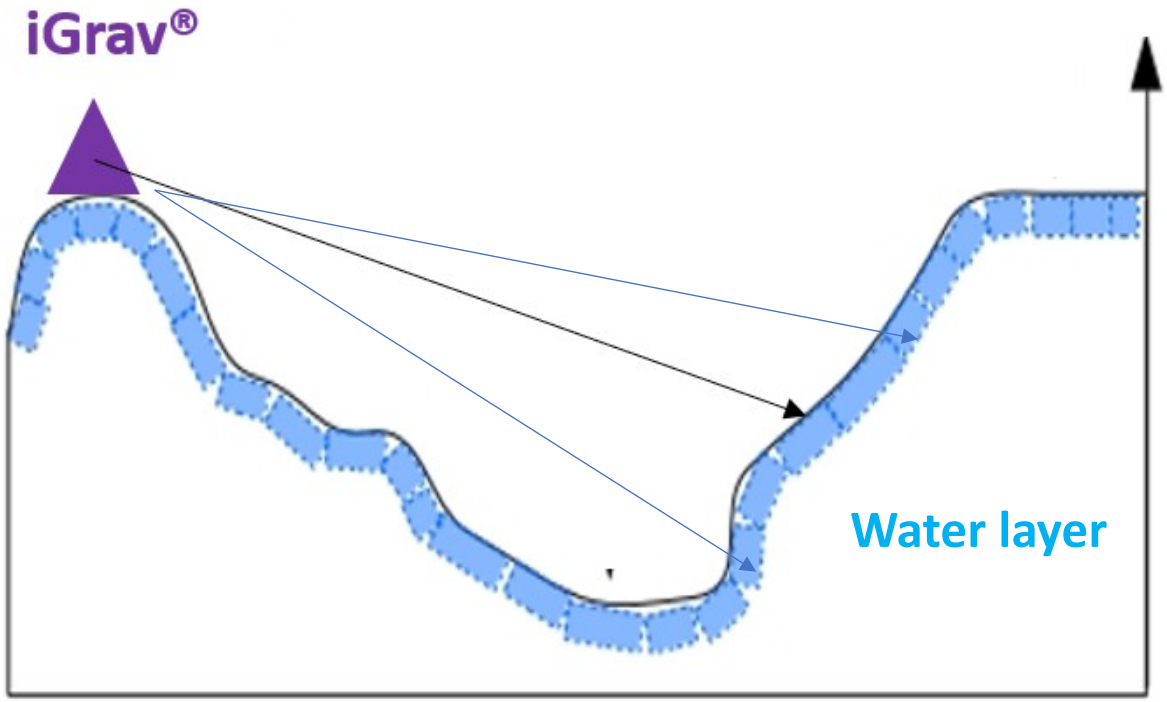


Estimation of basin water storage

- Water is distributed in an **homogeneous layer** covering the topography (Urbain, 2016).

- Gravity response of the water layer at the iGrav location:

$$g_{Storage}^{iGrav}(t) \equiv \sum_k \left(g_{Cube\,k}^{iGrav} \times Storage(t) \right)$$



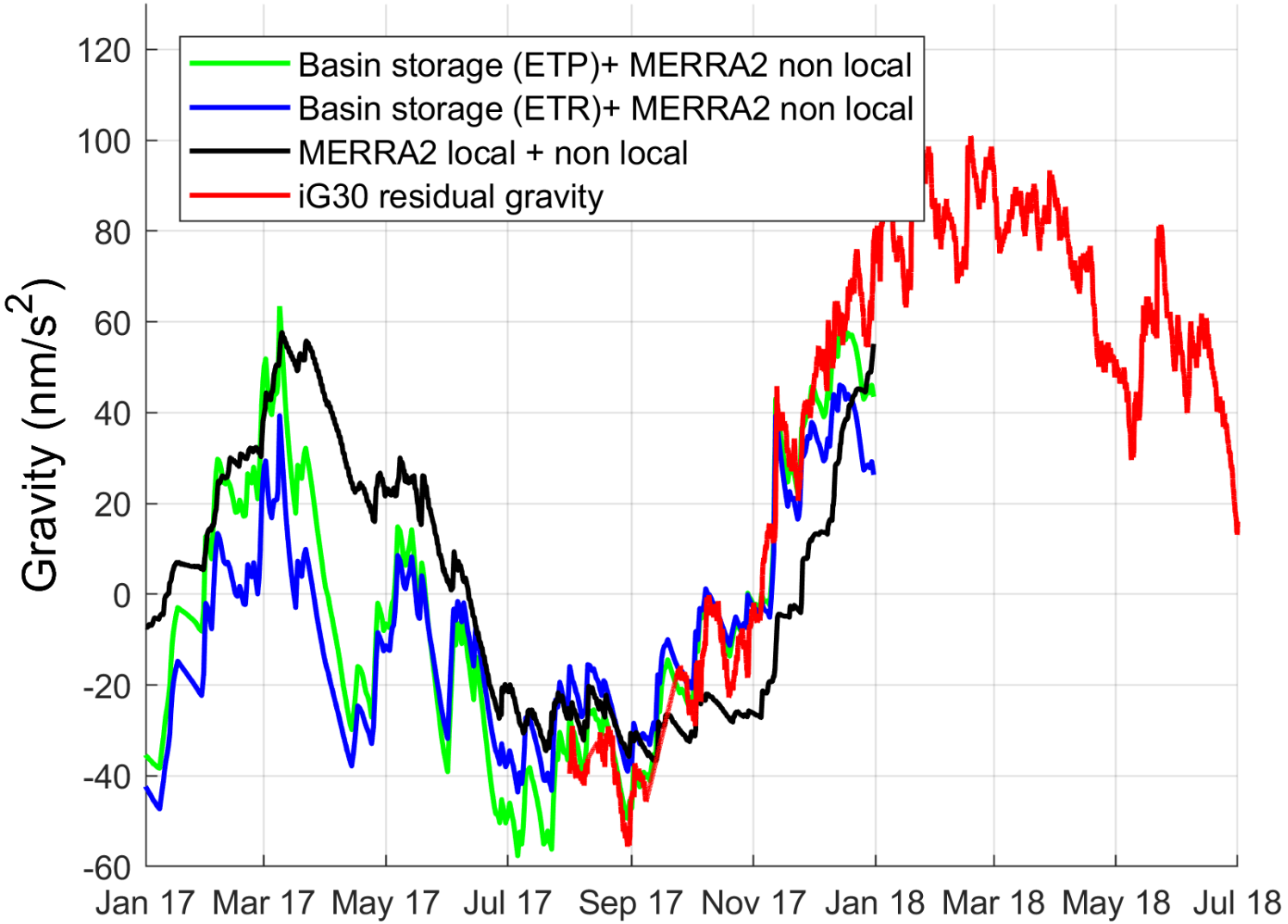
➡ Single relationship between water storage changes and gravity changes :

$$g_{Storage}^{iGrav}(t)\,[\mu gal] = 0{,}5988 \times Storage(t)\,[mm\ of\ water]$$

Comparison between hydrological residual signal and global/local hydrological models

- iG30 gravity = anual cycle with stronger amplitude.
- Due to **instrumental drift (unknown)** ?

→ Drift correction = 45 $nm.s^{-2}.year^{-1}$ from B.Fores et al., 2017



Comparison between hydrological residual signal and global/local hydrological models

- iG30 gravity = anual cycle with stronger amplitude.
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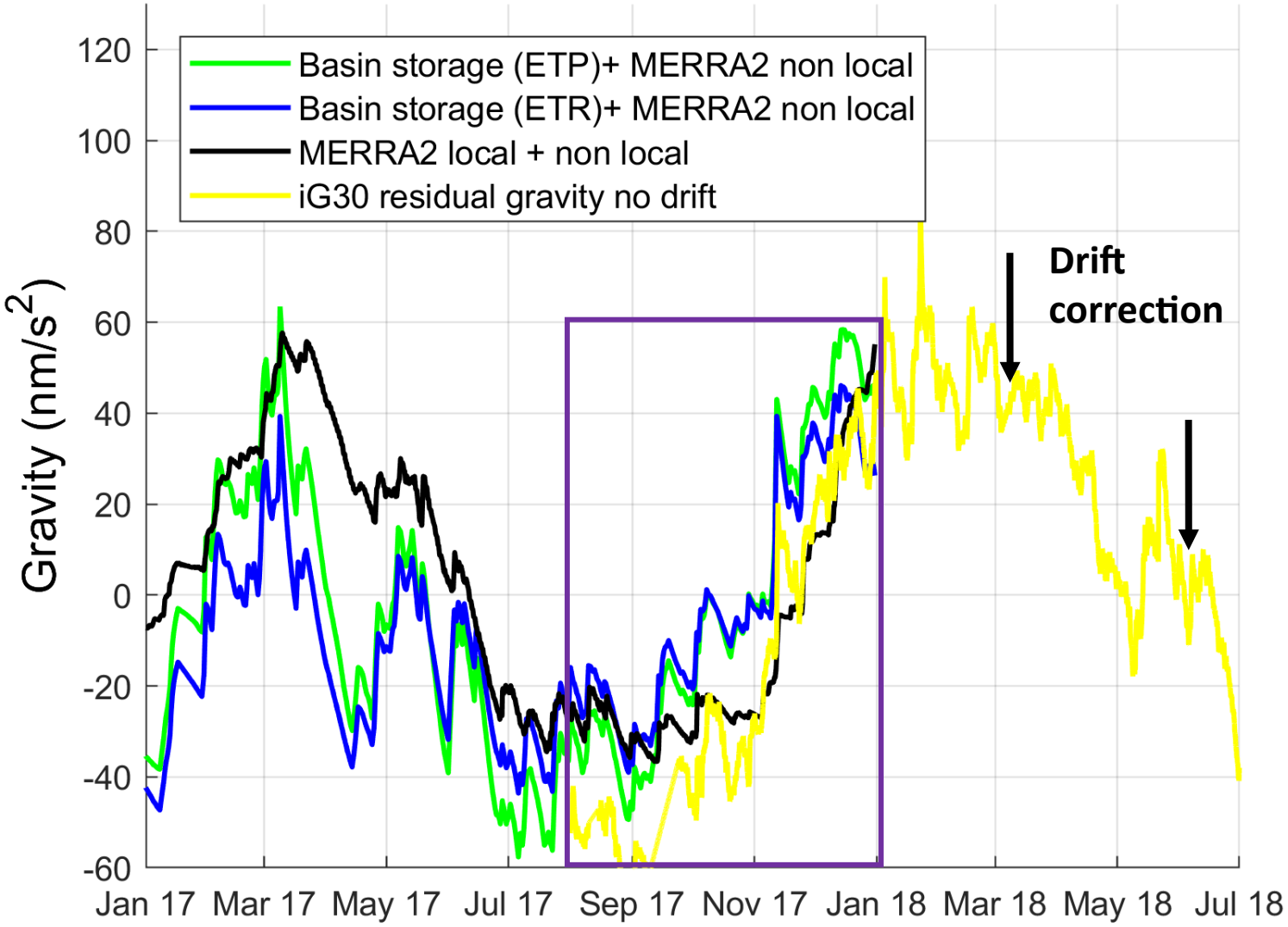
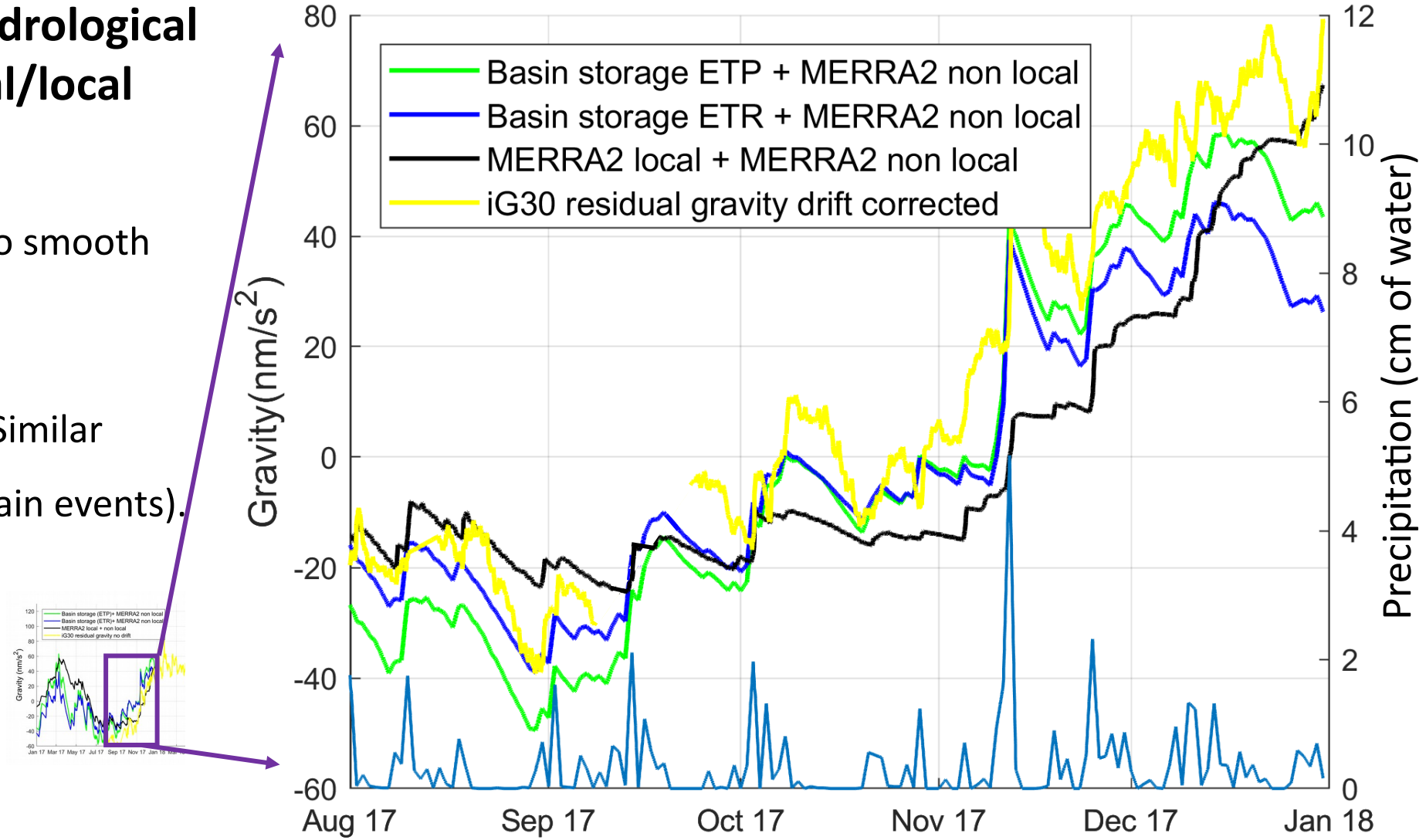
→ Drift correction = 45 nm.s^{-2}.year^{-1} from B.Fores et al., 2017

- Similar annual cycle between MERRA2 and drift corrected iG30 gravity : Annual cycle explained by regional hydrology.



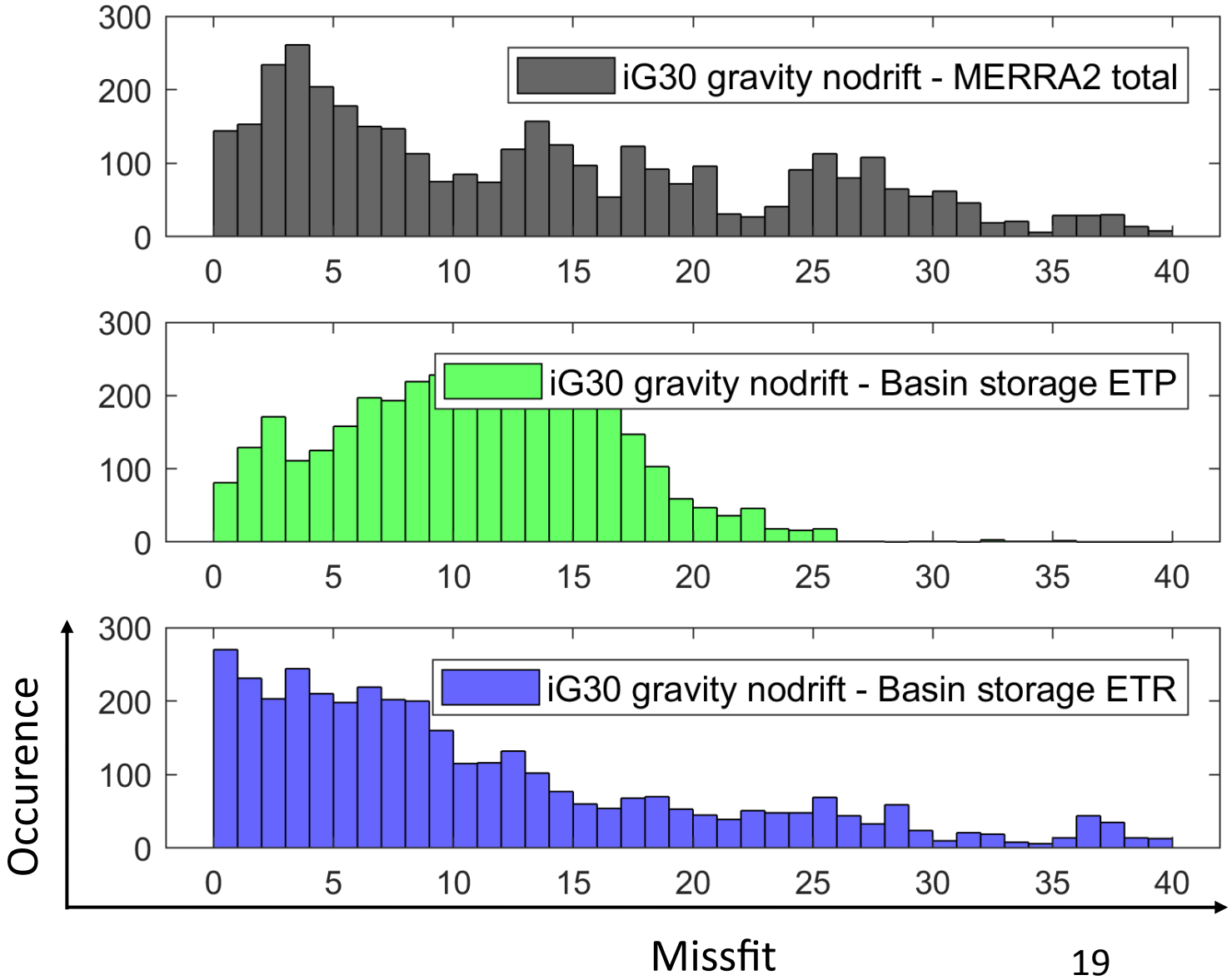
Comparison between hydrological residual signal and global/local hydrological models

- Global model MERRA2 : Too smooth compared to iG30 gravity.
- Local hydrological model: Similar high frequency pattern (rain events).



Comparison between hydrological residual signal and global/local hydrological models

- Global model MERRA2 : Too smooth compared to iG30 gravity.
- Local hydrological model: Similar high frequency pattern (rain events).
- Best adequacy between iG30 gravity and local ETR water storage.



Conclusion :

- Gravimetry applicable to complex hydro-system (**strong topography, high hydrological reactivity**).
- Regional hydrology explains the observed annual cycle.
- Local hydrology explains the observed short-term hydrological events.
- Residual missfit due to **iGrav drift** and a (too) simplistic model for water mass distribution.

Perspectives :

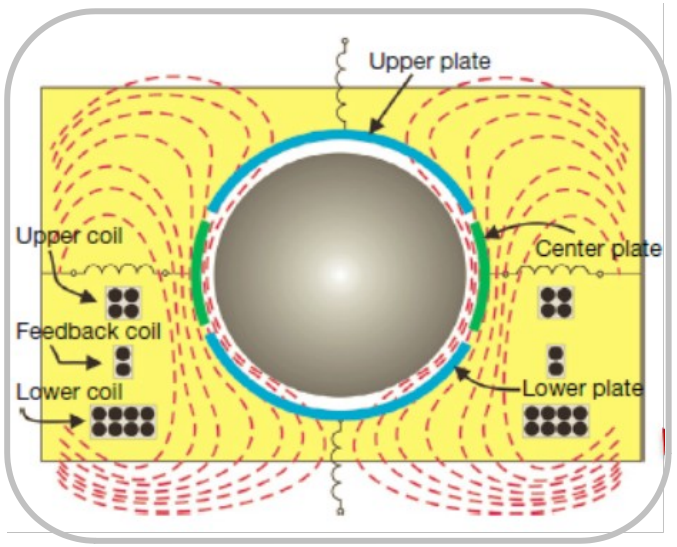
- iGrav drift will be estimated thanks to absolute gravity measurements (March 2019).

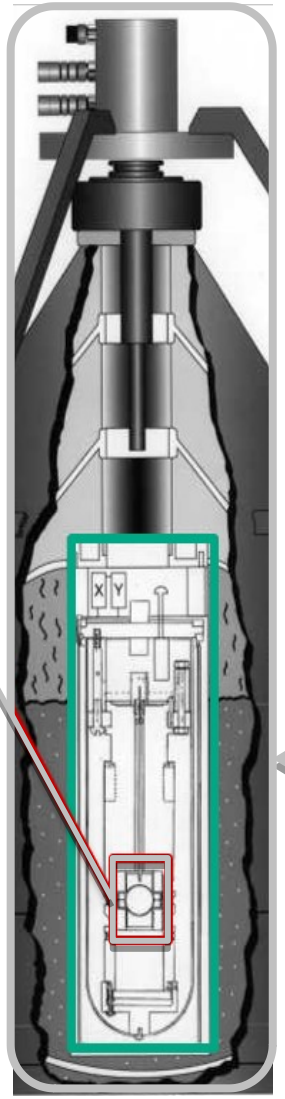
- Comparison between iGrav observations and a truly spatialised local hydrological model.
  (B.Jeannot et al. 2018, submitted)

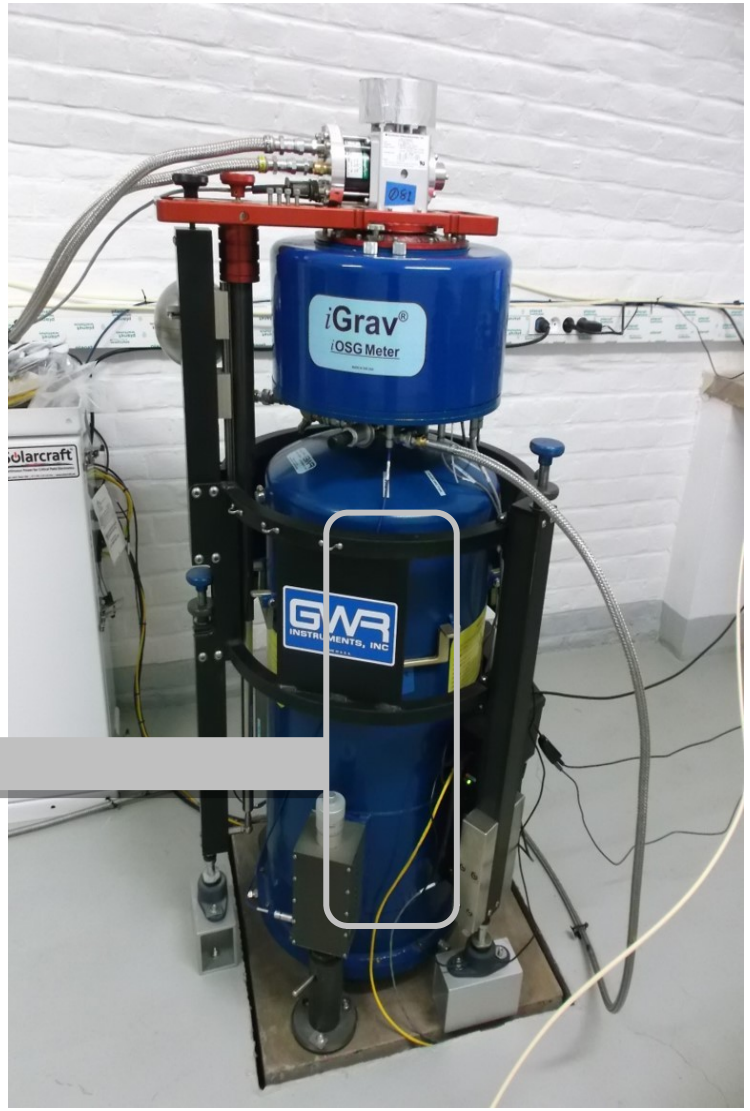
Thank for your attention !

Questions ?

Annex







Working principle of the super-conducting gravimeter iGrav®