Homogenization of GNSS IWV time series and estimation of climatic trends

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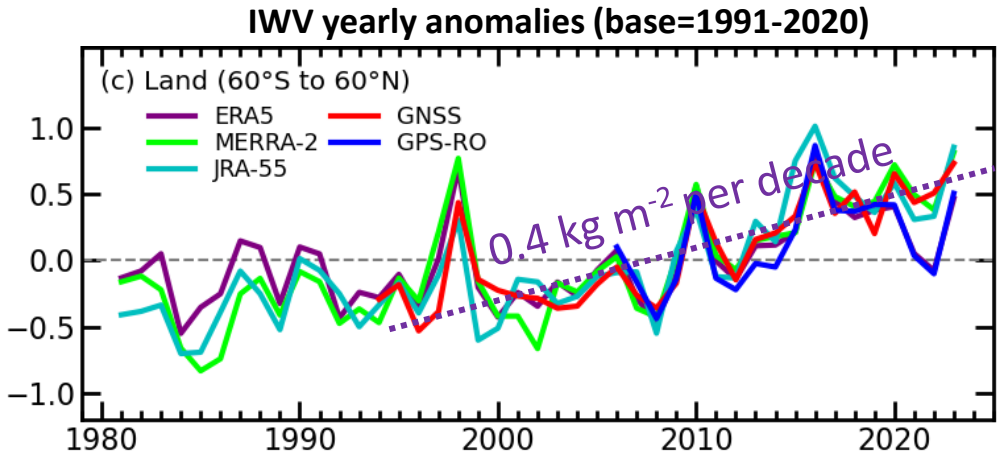
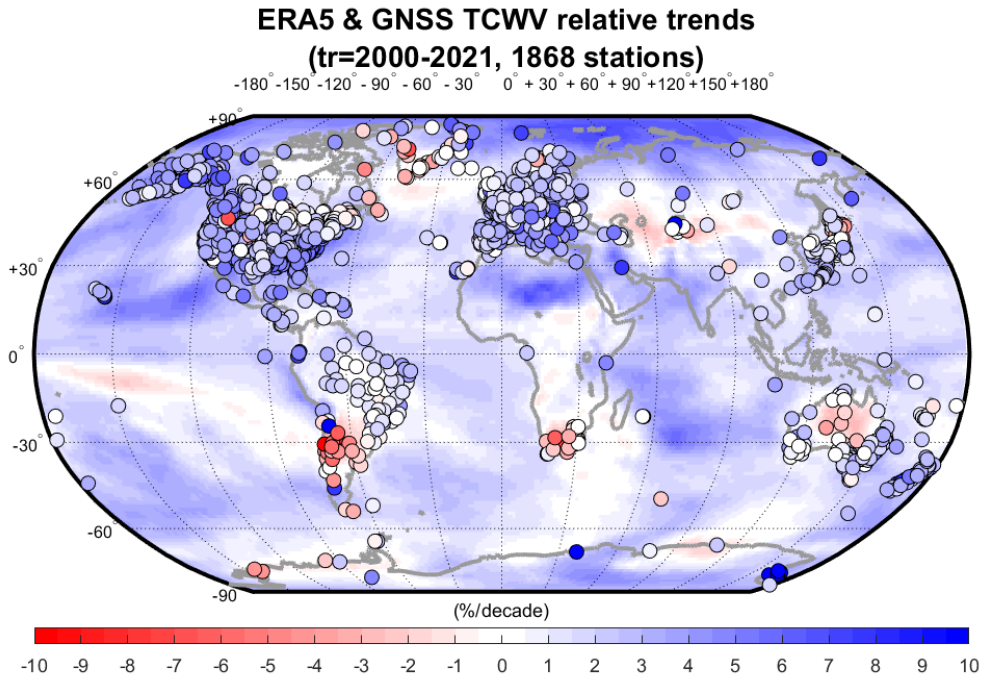
1. Objectives

- Long-term, high-quality GNSS IWV data
  - Monitor climate change and variability
  - Verify atmos. reanalyses and climate models
  - Bias correct model simulations/satellite obs.
- Goals/accuracy
  - IWV: < 0.5 kg m^{-2} (or 3%)
  - IWV trends: < 0.2 kg m^{-2} (or 1%) per decade
- Biases and bias changes/inhomogeneities

  are at the level of 0.5 - 1 kg m^{-2} [1, 2]
  - GNSS data processing changes
  - GNSS equipment changes
  - Changes in observation conditions
- Improve homogeneity of GNSS time series
  - At observation level (optimal GNSS data processing)
  - **Homogenize IWV time series (post-processing)**

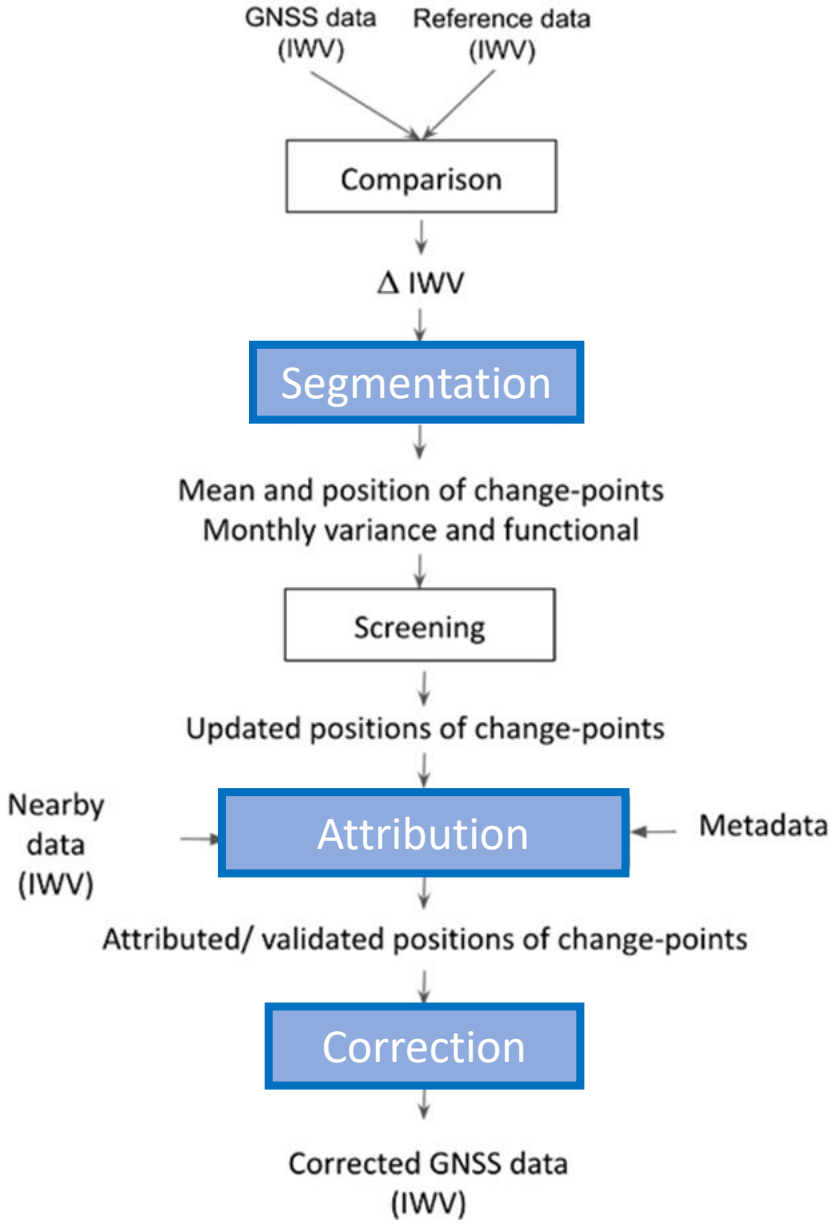




[*] Bock et al., AMS Baltimore, 2024

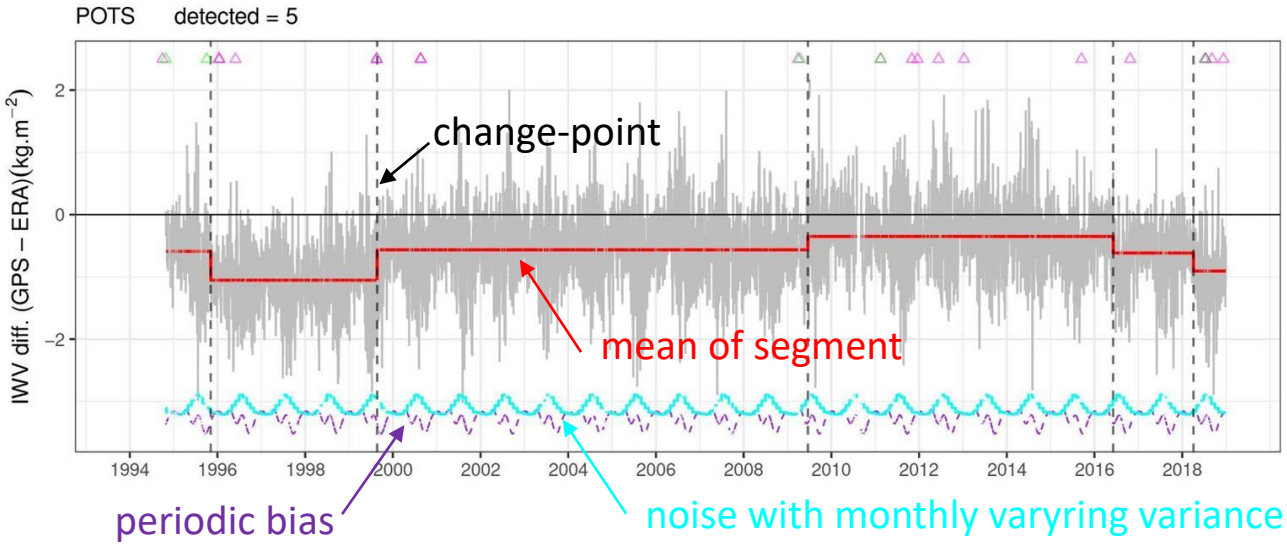
[1] Parracho et al., ACP, 2018; [2] Bock et al., AMT, 2022.

2. GNSS IWV homogenization procedure



Segmentation (GNSSseg):

- Detects the number of changes in mean and their positions
- Works on IWV difference series: GNSS - reanalysis
- Uses Penalized Maximum Likelihood method [3]

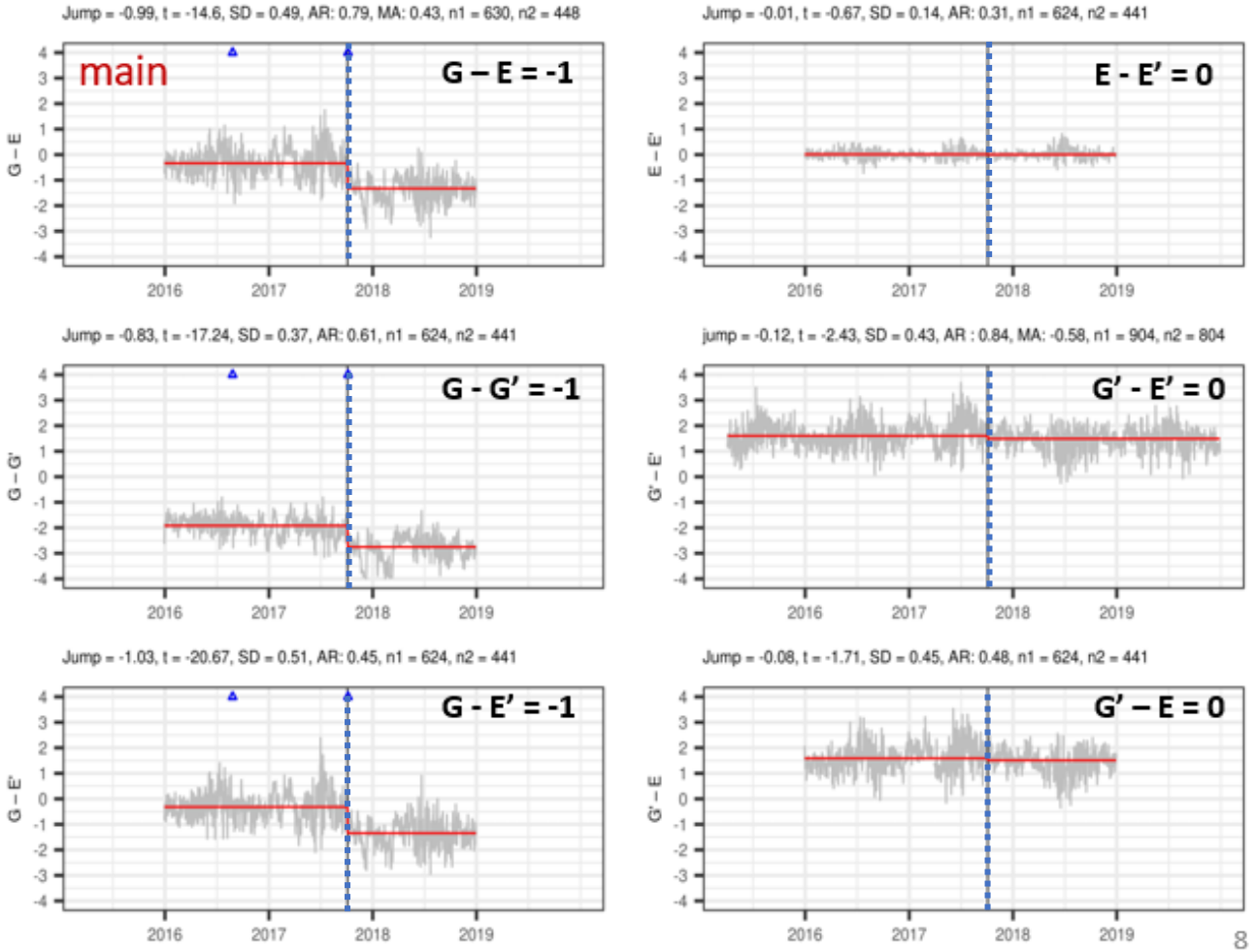


- is the change due to GNSS or reanalysis?

[3] Quarello et al., Remote Sensing, 2022

2. GNSS IWV homogenization procedure

Attribution (GNSS attr): predict if change-point is due to GNSS (G) or to the reanalysis (E)



main (G,E) & nearby (G',E') => 6 series of differences:
G-E, G-G', G-E', E-E', G'-E', G'-E

Test results

Logical table

Truth				Test results					
				1	2	3	4	5	6
G	E	G'	E'	G-E	G-G'	G-E'	E-E'	G'-E'	G'-E
-1	0	0	0	-1	-1	-1	0	0	0
-1	0	0	1	-1	-1	-1	-1	-1	0
-1	0	0	-1	-1	-1	0	1	1	0
-1	0	1	0	-1	-1	-1	0	1	1
-1	0	1	1	-1	-1	-1	-1	0	1
0	1	0	0	-1	0	0	1	0	-1

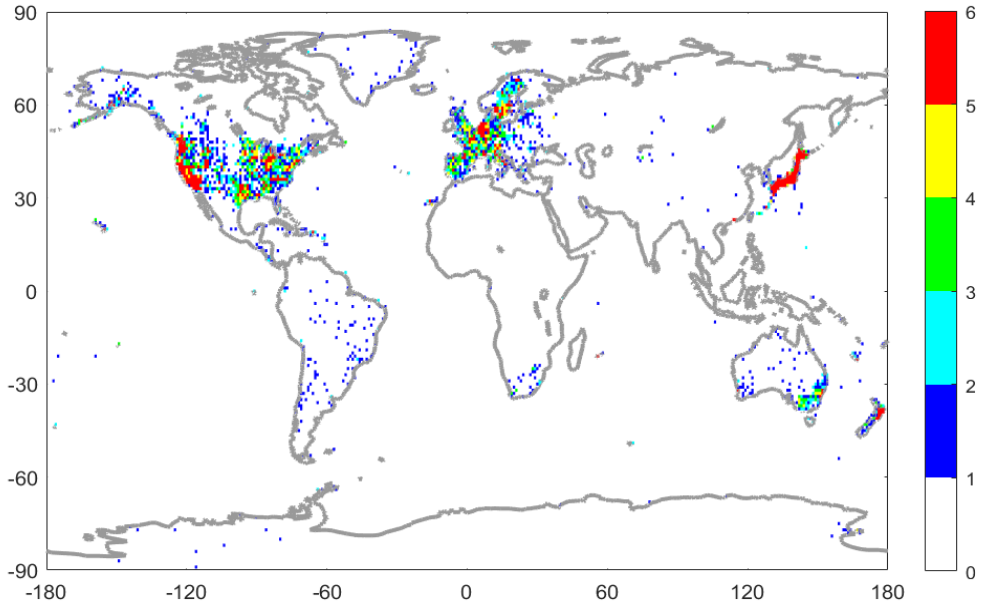
Prediction

FGLS test + Machine Learning classifier [5]

[5] Nguyen et al., Int J Climatol, 2024

3. Data sets

- JPL/IGS repro1 (120 stations, 1995-2010)
  - Development of segmentation method and GNSSseg & GNSSfast R packages [3]
- CODE/IGS repro2 (81 stations, 1994-2018)
  - Testing of segmentation method [4]
- CODE/IGS repro2 (81 main) & NGL repro3 (704 nearby)
  - Development of attribution method, classifier trained on 494 cases [5]
- NGL repro3 (6048 stations, 1994-2022)
  - New classifier trained on 13,615 cases [Nguyen, in prep]

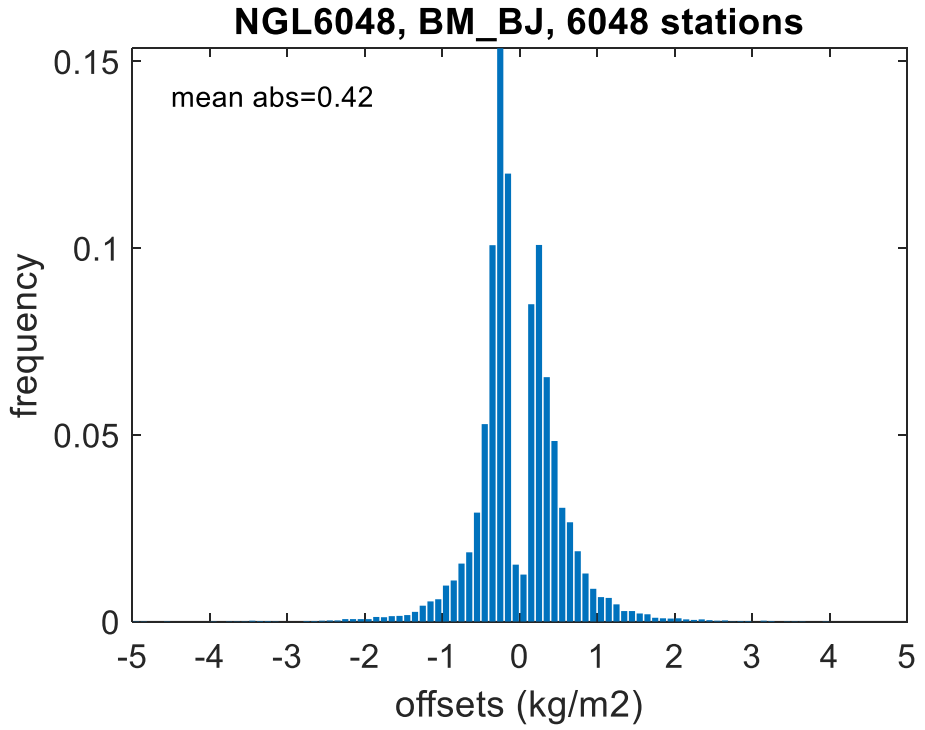


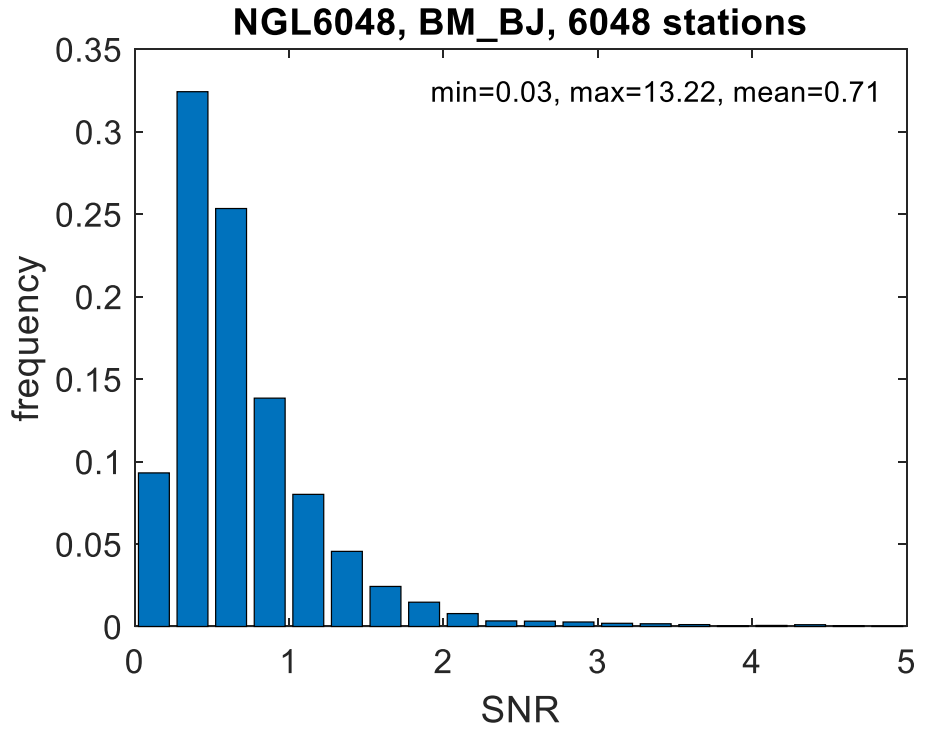
Number of stations per 1°x1° grid cell

[3] Quarello et al., Remote Sensing, 2022
[4] Nguyen et al., Atmosphere, 2021
[5] Nguyen et al., Int J Climatol, 2024

4. Segmentation results

- Consistent results between all three datasets (JPL/IGS, CODE, NGL):
  - Mean number of change-points per station = 1.5 to 1.7 every 10 years
  - 10% stations have homogeneous series (no change-point detected)
  - IGS stations: metadata validate 32% to 36% detections (Antenna/Radome, Receiver, Cutoff)
  - NGL stations: lacking metadata (9% validated)

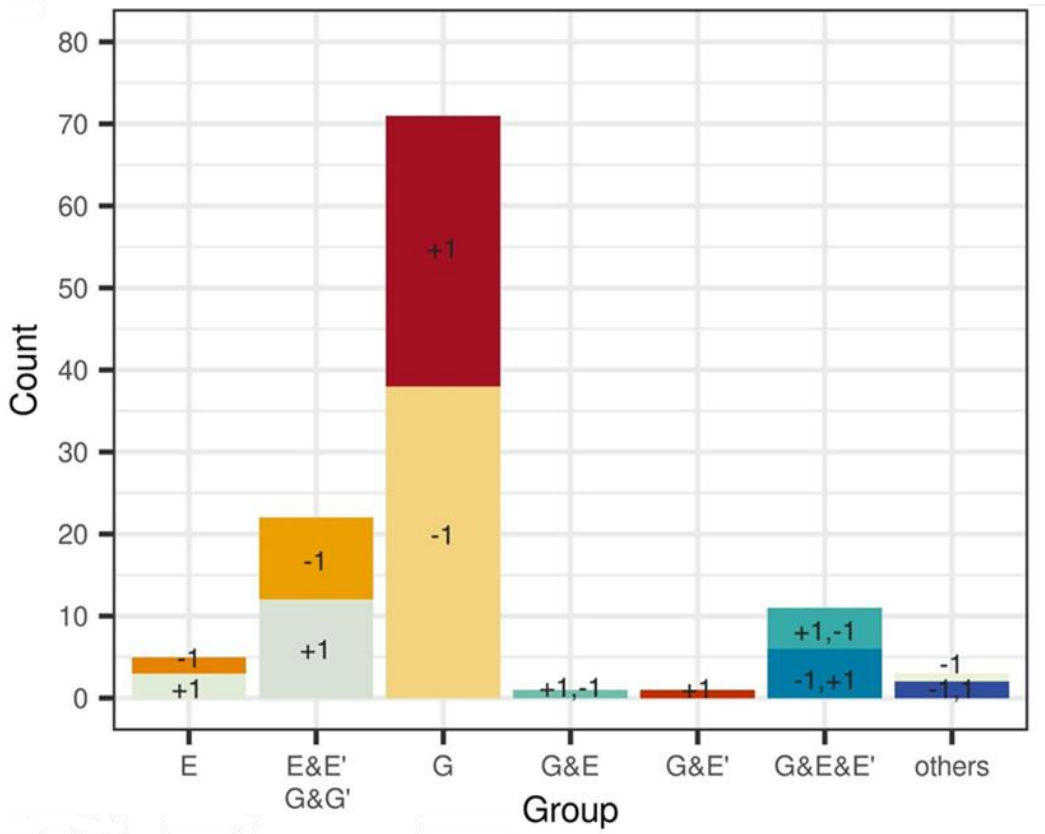




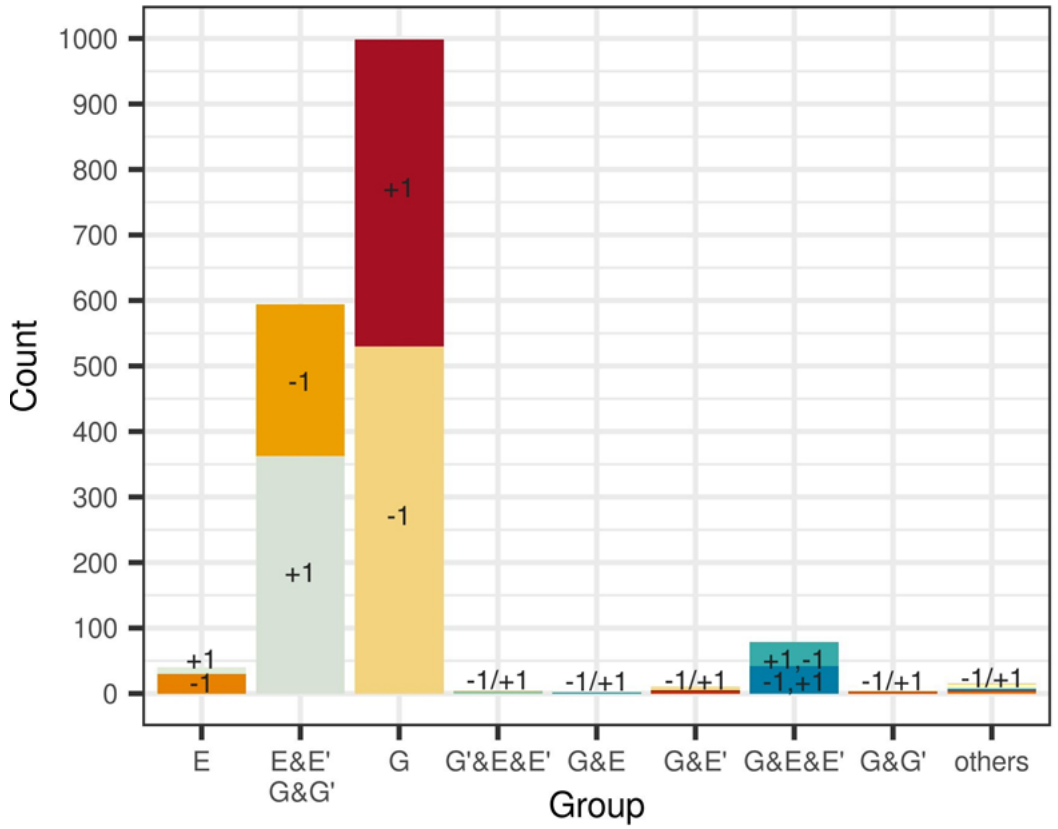
5. Attribution results

- CODE repro2 (81 main) & NGL repro3 (704 nearby)
  - *114 change-points attributed in 49 main stations =>* ***62% due to G and 19% to E&E'***
- NGL repro3 (selected 632 main stations having 20+ yrs series)
  - *1748 change-points attributed in 628 main stations =>* ***57% due to G and 34% to E&E'***

CODE repro2



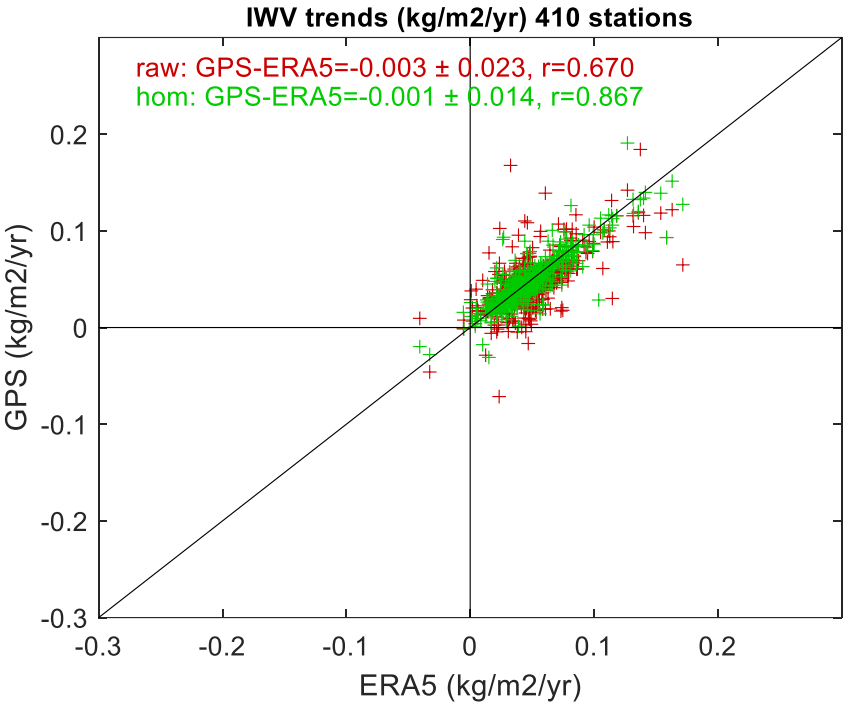
NGL repro3



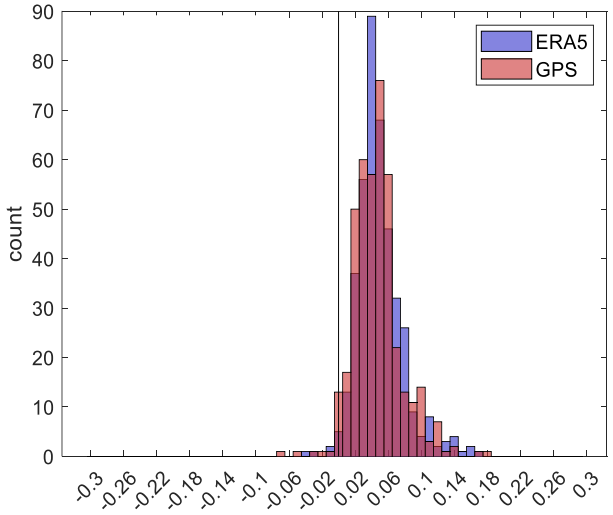
6. Trend results

- NGL repro3 (410 stations fully homogenized)
- IWV anomaly trends estimated by FGLS – AR(1)

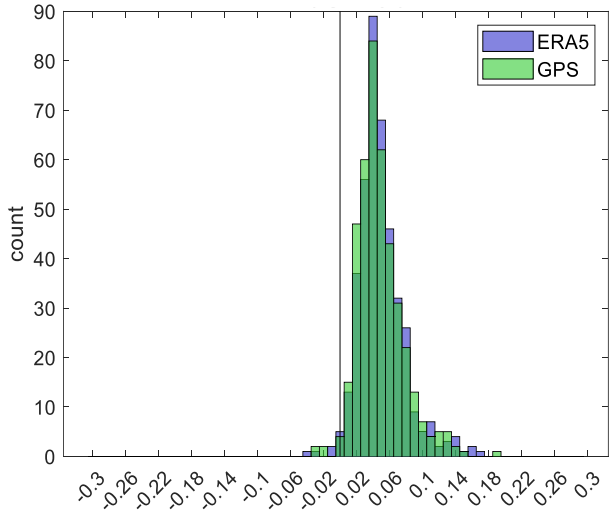
Mean trend (kg/m2/yr)
ERA5 = 0.050 / GPS raw = 0.047 / GPS hom = 0.049
Standard error (kg/m2/yr)
0.020
Fraction of significant trends (α=0.05)
ERA5 = 68% / GPS raw = 64% / GPS hom = 70%

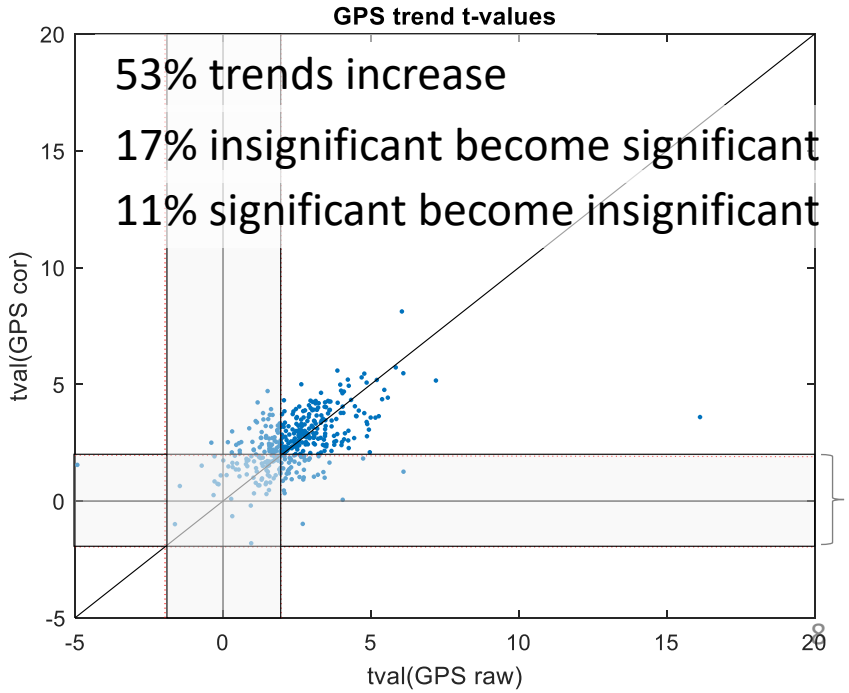


raw

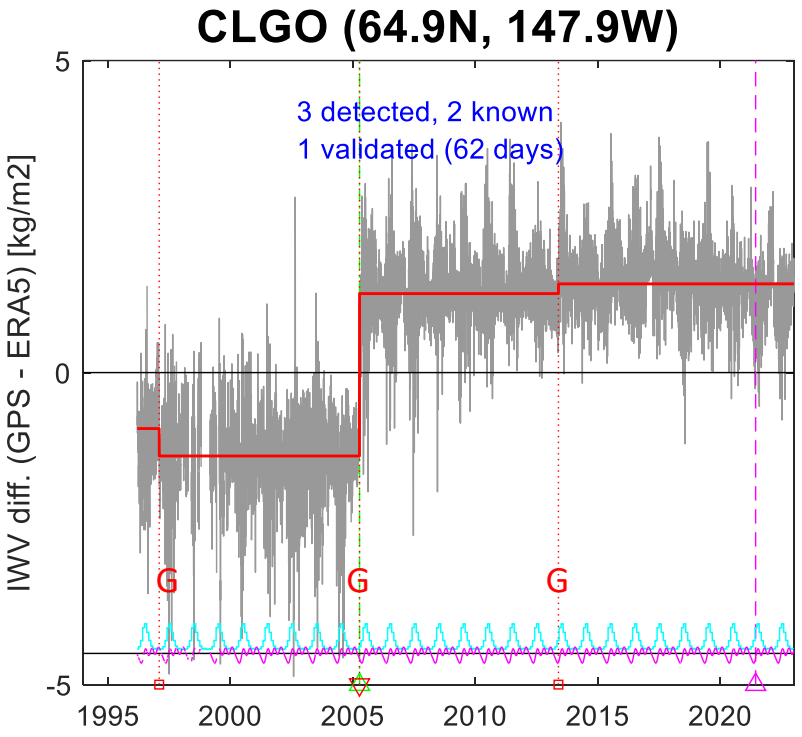


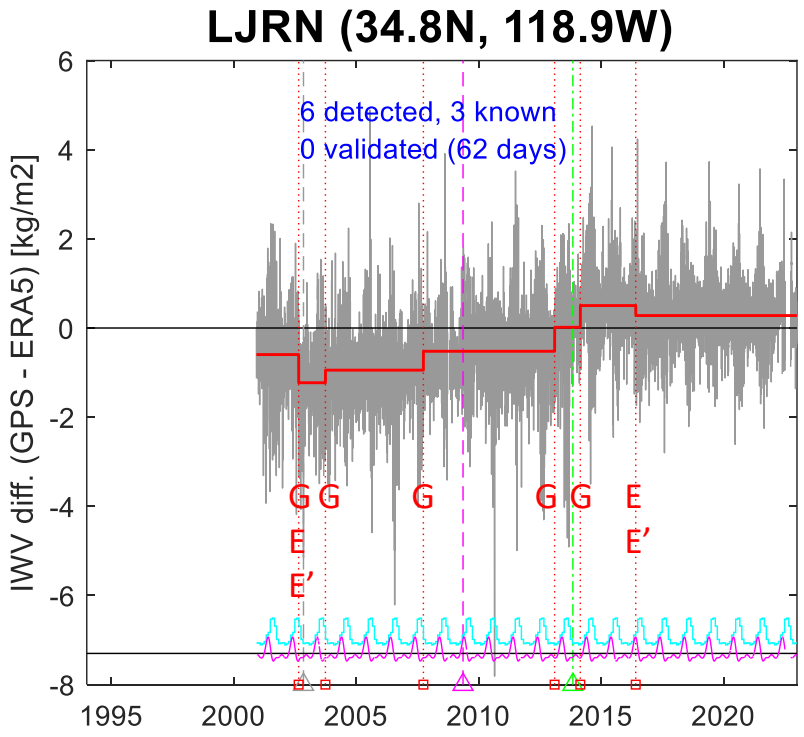
homogenized

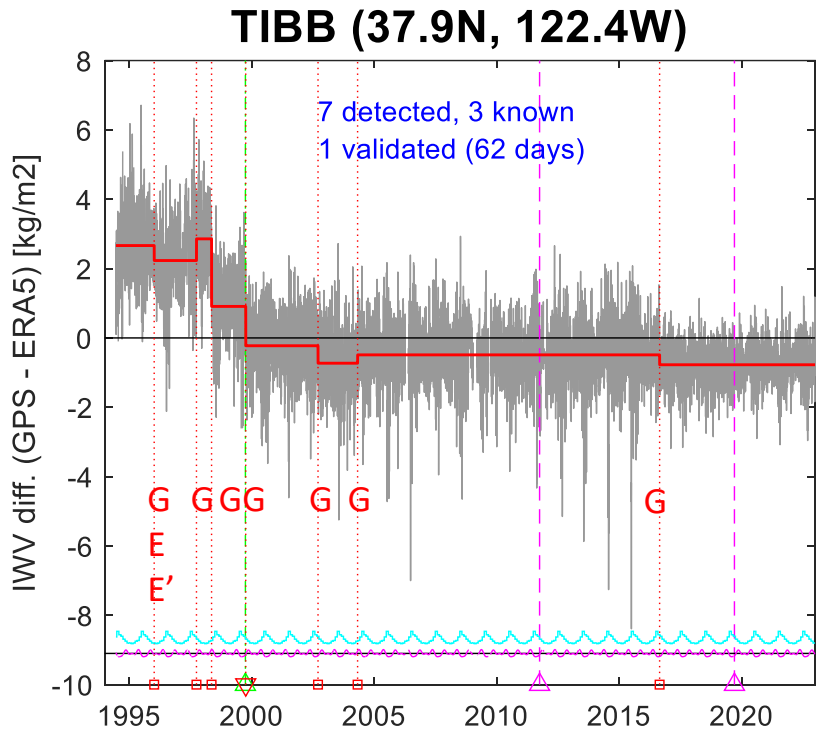




7. Impact of homogenization on linear trend estimates







CLGO trend

Raw = 0.168 kg/m2/yr

Hom = 0.036 kg/m2/yr

LJRN trend

Raw = 0.102 kg/m2/yr

Hom = 0.021 kg/m2/yr

TIBB trend

Raw = -0.071 kg/m2/yr

Hom = 0.022 kg/m2/yr

Conclusions and perspectives

- Homogeneity of reprocessed GNSS data sets (IGS repro1, CODE repro2, NGL repro3):
  - Mean number of change-points per station = 1.5 to 1.7 every 10 years
  - 10% stations have homogeneous series (no change-point detected)
  - 60% change-points attributed to GNSS, 20 to 30% to reanalysis (TBC), 10 to 20% other causes.
- Impact on trends:
  - Mean impact is small but trends are slightly increasing on average
  - 28% trends are significantly changed (in both directions)
- R packages for segmentation and homogenization of ZTD or PW time series:
  - GNSSseg https://cran.r-project.org/web/packages/GNSSseg/index.html (Quarello et al., 2022)
  - GNSSfast https://github.com/arq16/GNSSfast (fast version of GNSSseg, using pruned DP)
  - GNSSattr https://github.com/khanhninhnguyen/GNSSattr (based on Nguyen et al., 2024 -> beta release)
  - *GNSShom: a complete package for homogenization (in prep)*

- Next step: improve ZTD accuracy and homogeneity at obs. processing level
  - **IAG JWG C.8 Optimal processing and post-processing of GNSS-PW climate data records**

  => Splinter meetings: today 4:00pm in room B78 + tomorrow 4:30pm in troposphere session