Comparison of GNSS IWV processing strategies from the point of view of climate monitoring

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Motivation

- Zenith total delay (ZTD) accuracy dominates the error budget of integrated water vapour (IWV).
- Adopting of various GNSS processing strategies caused differences in ZTD.
- In this study we assessed the impact of processing strategies on GNSS IWV long-term parameters, especially trends, which can be used in various climate applications.

ZTD estimation according to various processing strategies

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ZTD to IWV conversion

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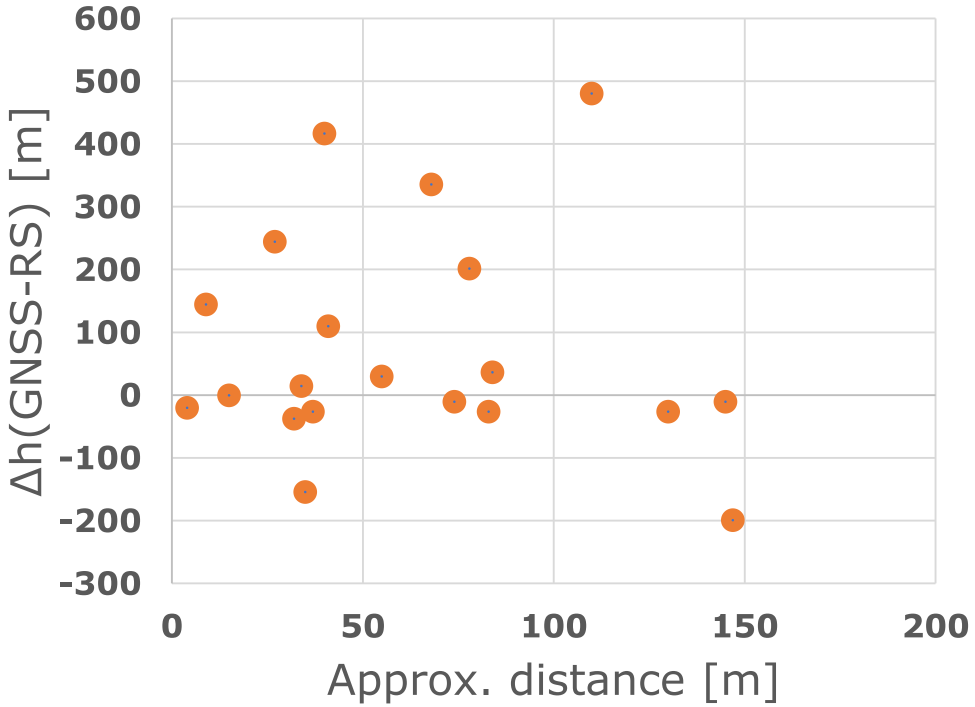
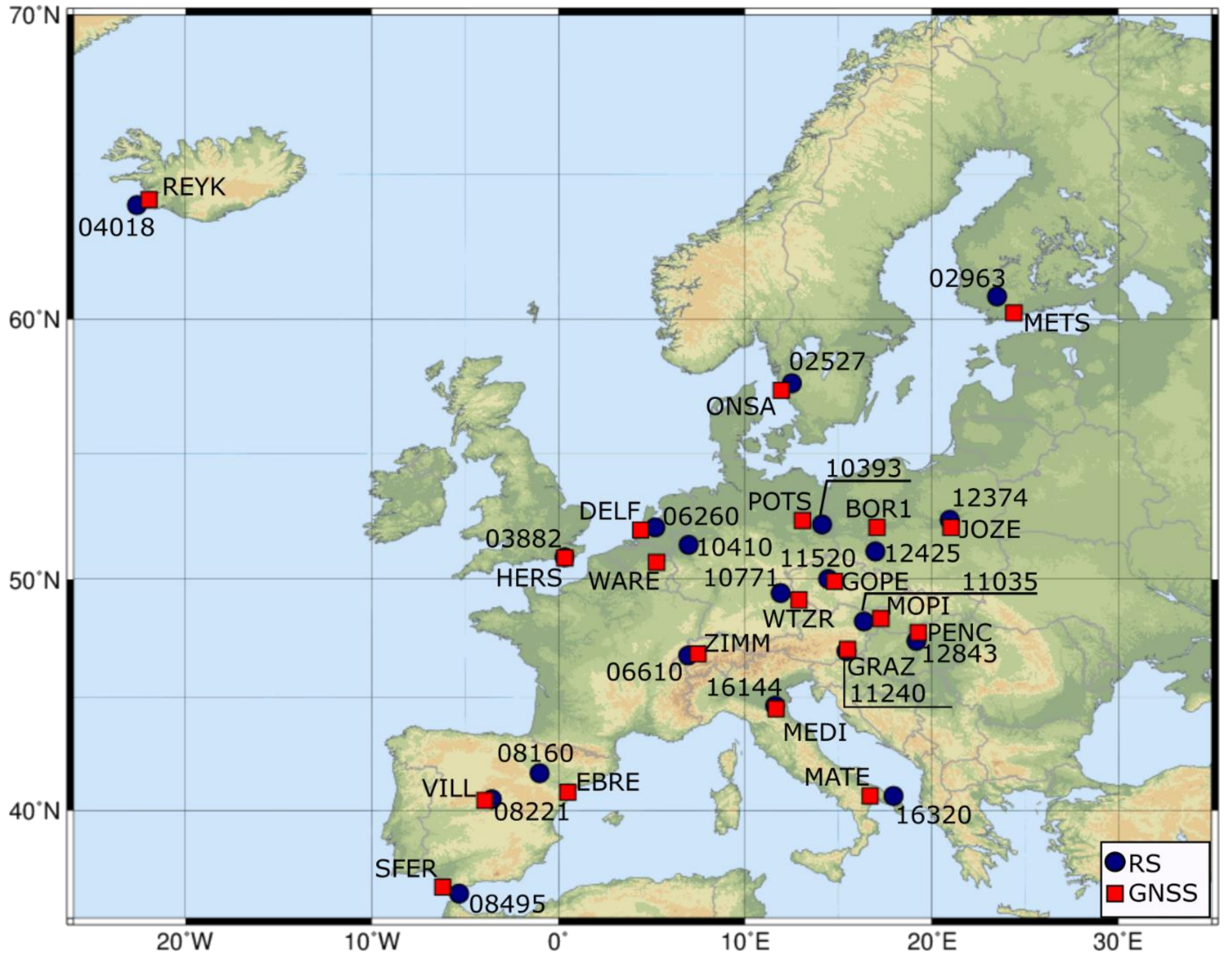
GNSS IWV comparison to RS IWV

Data

- 20 EPN GNSS stations
- 20 RS stations
- GPS observations: since 01.1996 to 01.2016





ZTD processing

- 8 different processing strategies with different softwares, positioning method, tropospheric delay mapping functions, a priori ZHD, and cut-off angle.

	BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
software	Bernese 5.2	Bernese 5.2	Bernese 5.2	Bernese 5.2	GAMIT 10.50	GAMIT 10.50	GAMIT 10.50	GAMIT 10.50
method	PPP	PPP	DD	DD	DD	DD	DD	DD
a priori ZHD	VMF1	GPT	VMF1	GPT	VMF1	STP	GPT2	VMF1
Tropospheric mapping function	VMF1	GMF	VMF1	GMF	VMF1	Niell	GPT2	VMF1
cut-off angle	5°	5°	5°	5°	5°	5°	5°	20°

ZTD to IWV conversion

- IWV can be obtained using ZWD:

$$ZTD = ZHD + ZWD \rightarrow ZWD = ZTD - ZHD$$

$$IWV = \Pi(T_m) \cdot ZWD$$

- ZHD value can be also obtained using rather the accurate Saastamoinen hydrostatic model:

$$ZHD = \frac{0.0022767 * P}{1 - 0.0026 * \cos 2\varphi - 0.00000028 * h}$$

where φ is the ellipsoidal latitude, and h is the height in [m], P is the total air pressure in [hPa], T is the temperature in [K].

- $\Pi(T_m)$ is a dimensionless quantity which can be obtained from the mean weighted temperature of the atmosphere T_m

$$\Pi^{-1} = 10^{-8}\left(R_v \ * \ (K_3 T_m \ + K_2' \ )\right)$$

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from ERA-Interim

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const. values

ERA-Interim validation

- We performed validation of P and T_m derived from ERA-Interim.
- 20 RS stations located near GNSS stations were used.

- We calculate surface pressure for station locations using the following steps:
  - ✓ four nearest grid nodes to the station are selected,
  - ✓ P at these nodes is converted to sea pressure (P_{sea}):

$$P_{sea} = P \cdot \left(\frac{1 - 0.0065h}{T + 0.0065h} \right)^{-5.257}$$

  - ✓ P_{sea} is interpolated at the station latitude and longitude using bilinear interpolation and converted to P at the station altitude using transformed above equation.

ERA-Interim validation

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- 20 RS stations located near GNSS stations were used.

- In the case of T_m based on the ERA-Interim profiles we estimated T_m using:

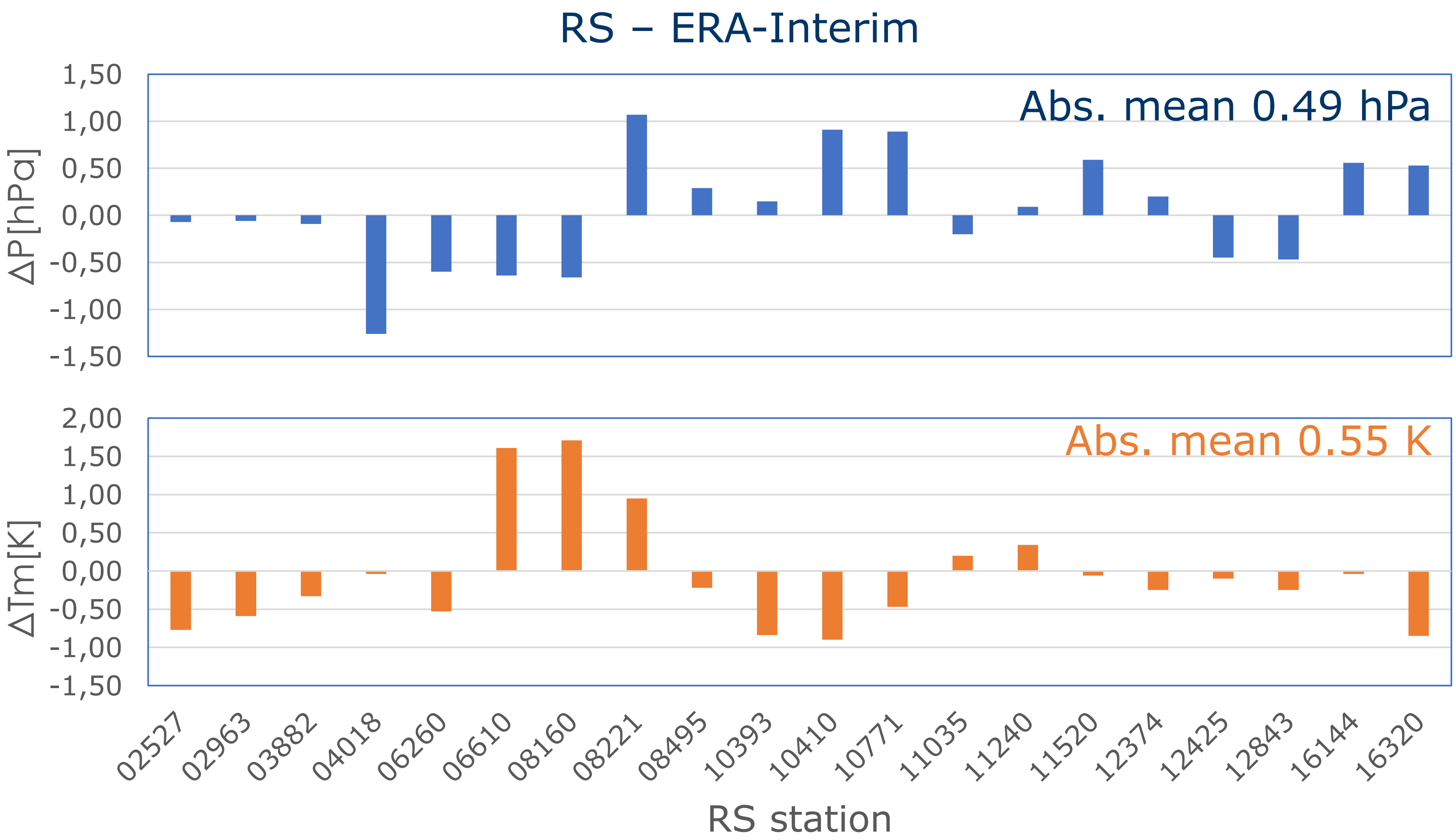
$$T_m = \frac{\int \frac{e}{T} dh}{\int \frac{e}{T^2} dh}$$

T is the temperature in [K], e is the water vapour pressure in [hPa]

- and then performed a bilinear interpolation to obtain its value at the station location. We did not apply any height corrections.

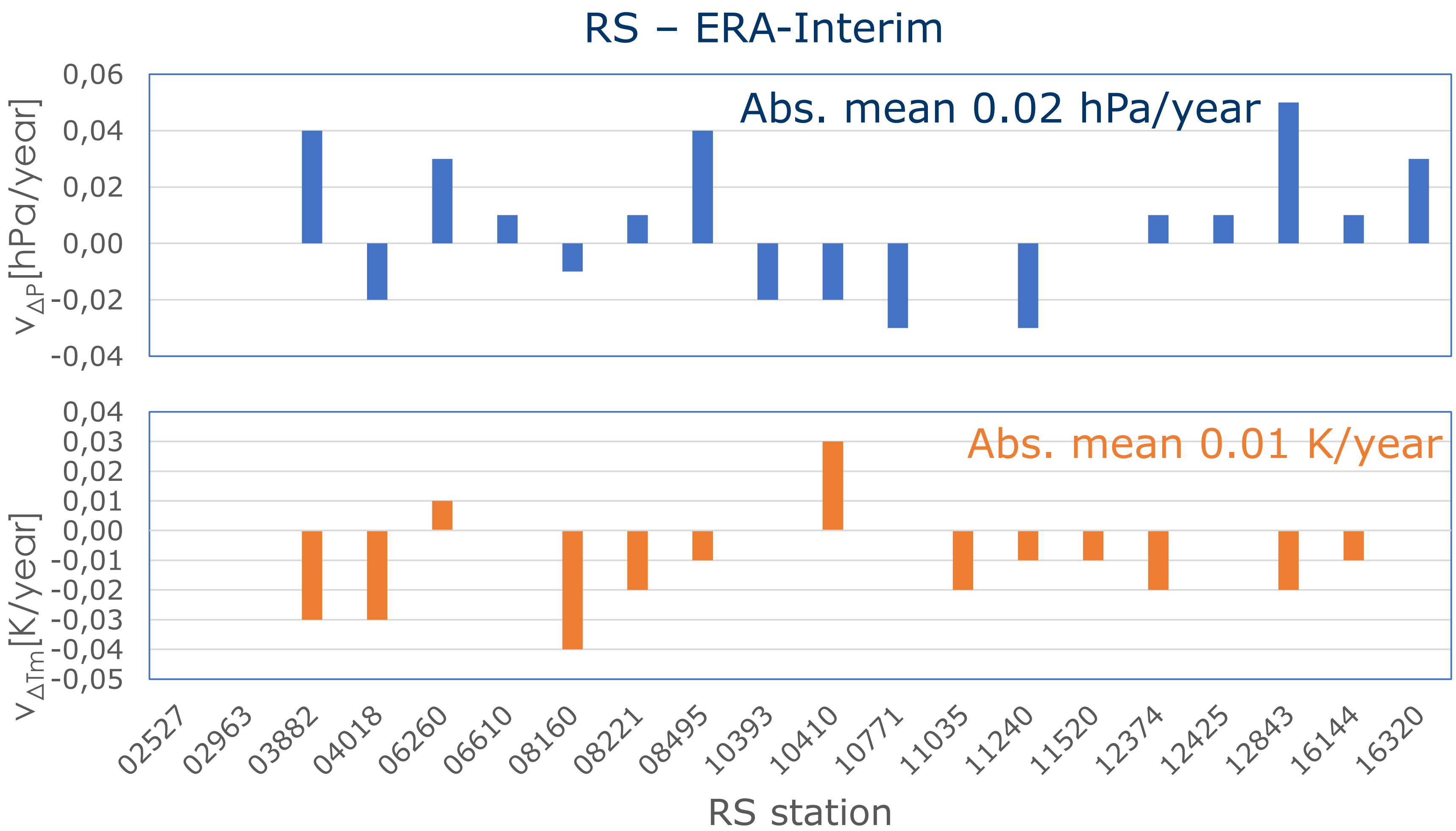
ERA-Interim validation

- Mean differences of P and T_m between RS and ERA-Interim



ERA-Interim validation

- Linear trends of the P and T_m differences between RS and ERA-Interim

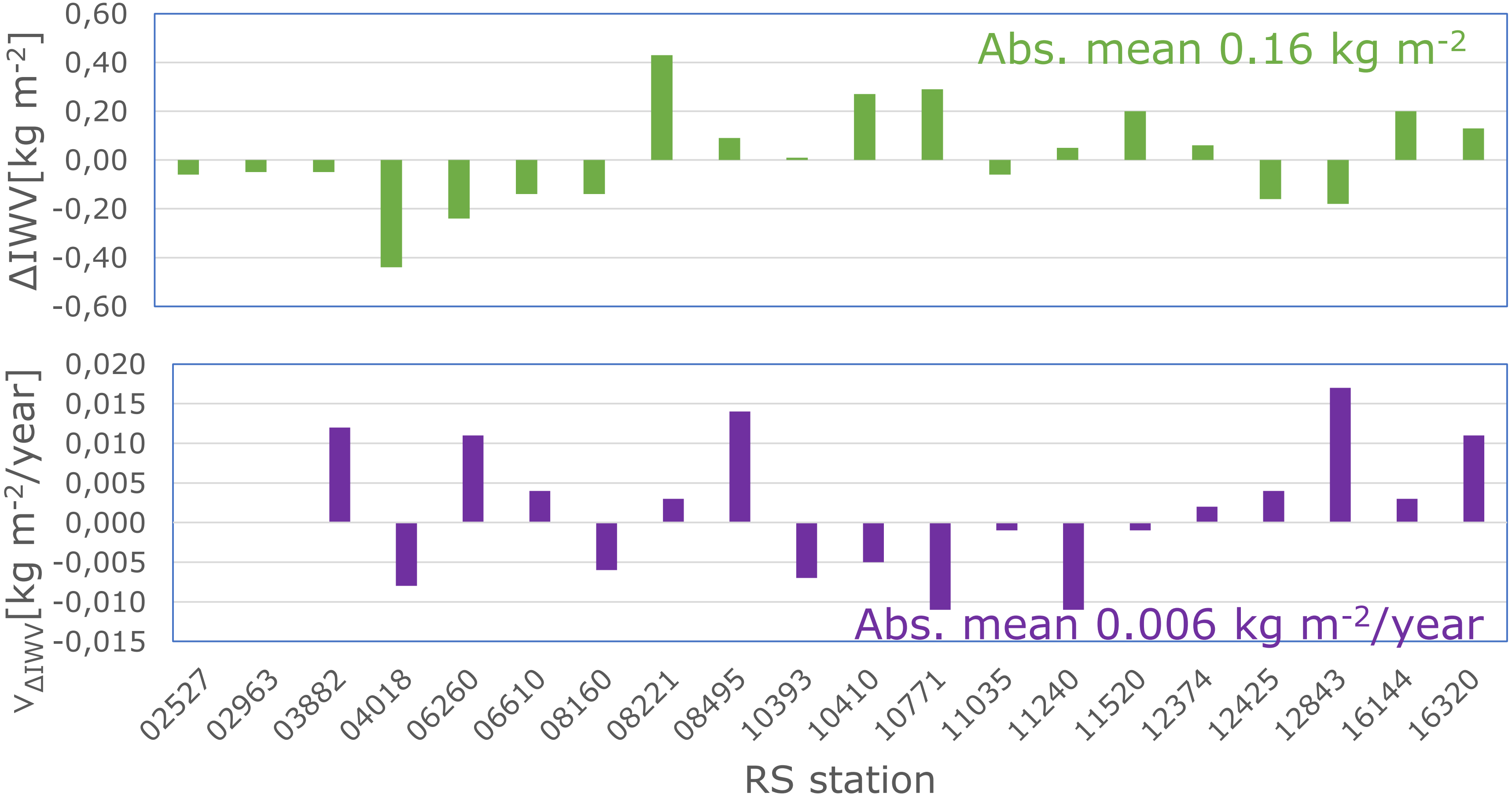


ERA-Interim validation

- How these differences translates into IWV values and its linear trends?
- We estimated uncertainties of P and T_m for each RS station and then we estimate uncertainties of IWV.

ERA-Interim validation

- How these differences translates into IWV values and its linear trends?



IWV long-term parameters estimation

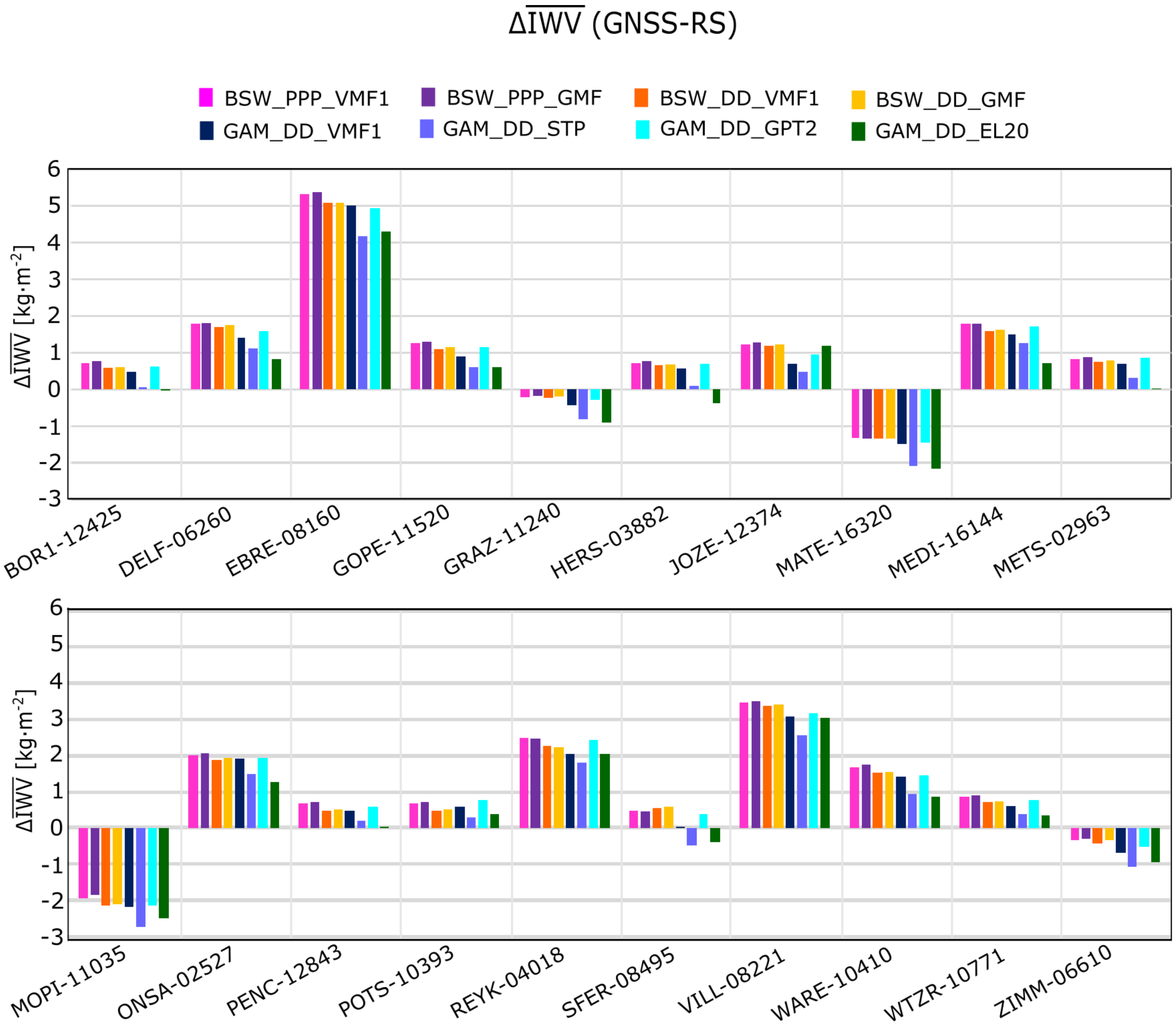
- We estimated an annual and semi-annual oscillations and linear trends for each GNSS and RS station and solution.
- This was done according to the following model:

$$x(t) = x_0 + v_x t + A_A^I sin2\pi t + A_A^O cos2\pi t + A_{SA}^I sin4\pi t + A_{SA}^O cos4\pi t + \cdots$$

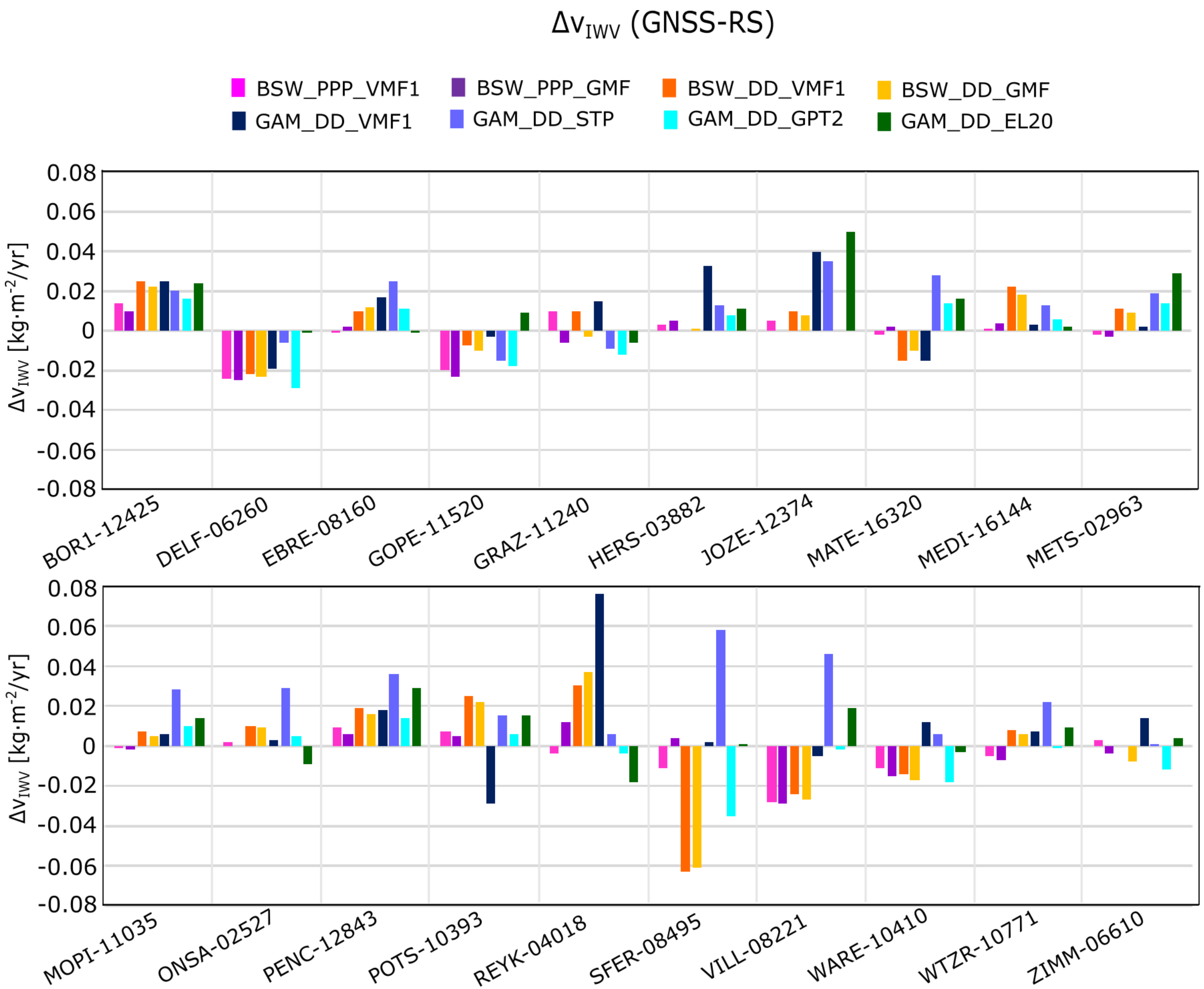
where $x(t)$ is the observed time series,
$v_x t$ is the linear trend, A_A^O A_A^I etc.

- The number of concerned sine and cosine conditions was chosen individually for each station by making Lomb-Scargle periodograms.
- Long-term parameters from GNSS IWV and RS IWV were then compared.

Results – mean value of IWV



Results – IWV linear trend



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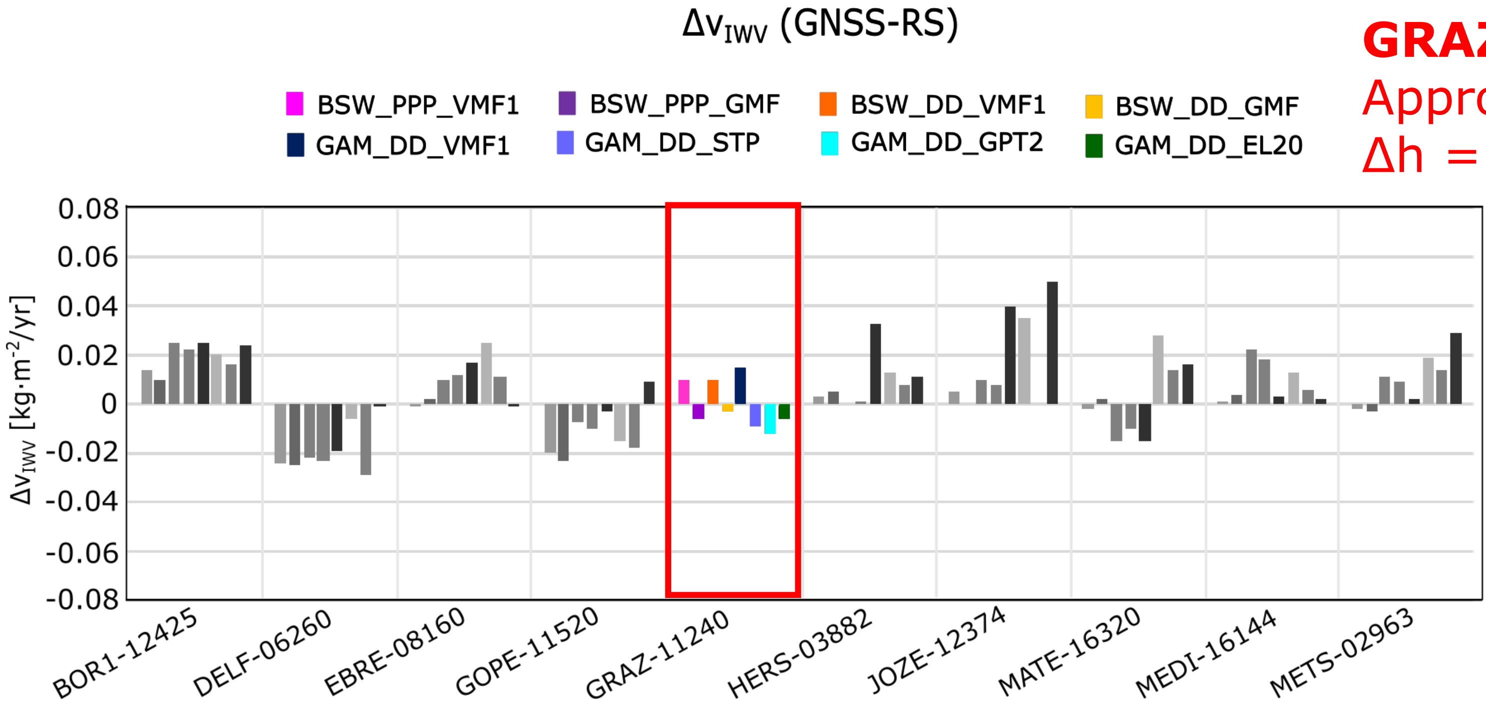


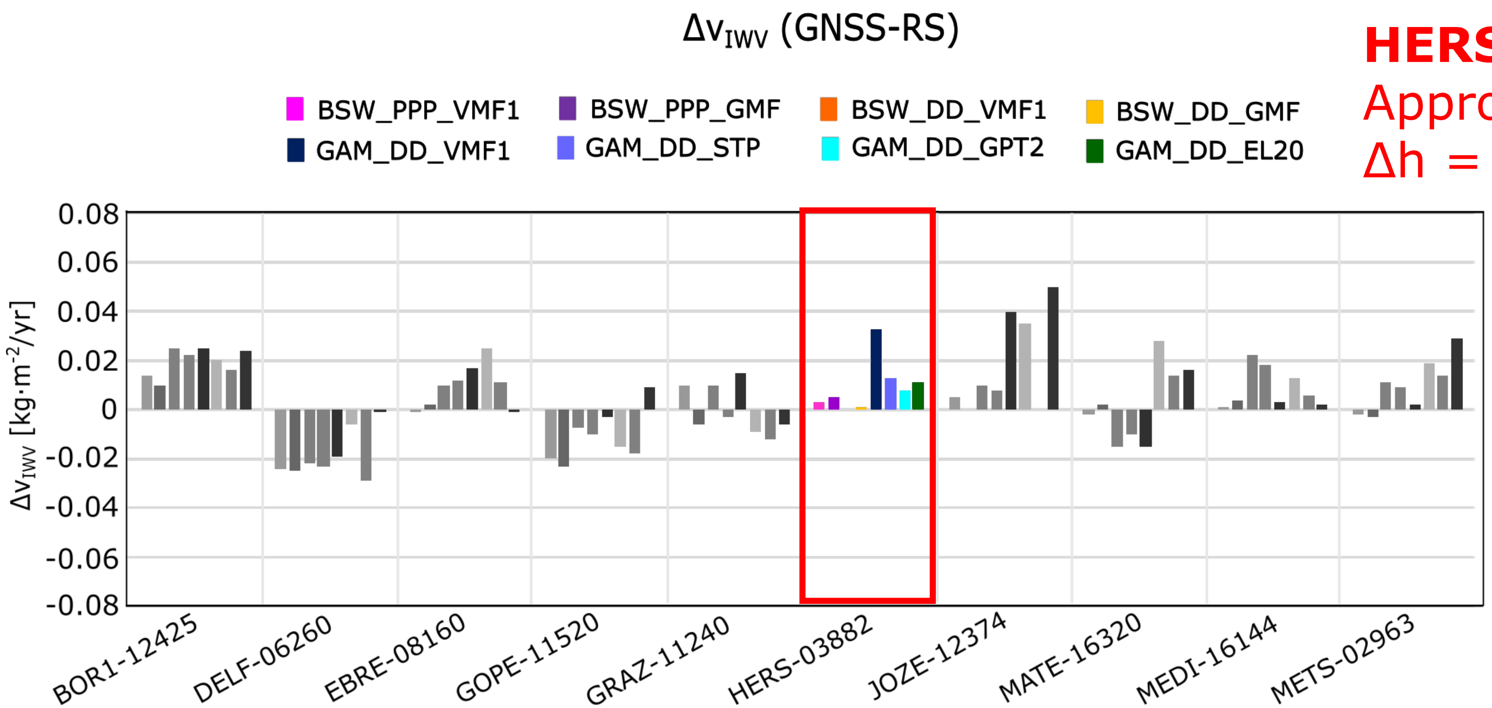
GRAZ - 11240

Approx. dist. ~9 km

Δh = 144 m

GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
GRAZ	11240	0.010	-0.006	0.010	-0.003	0.015	-0.009	-0.012	-0.006

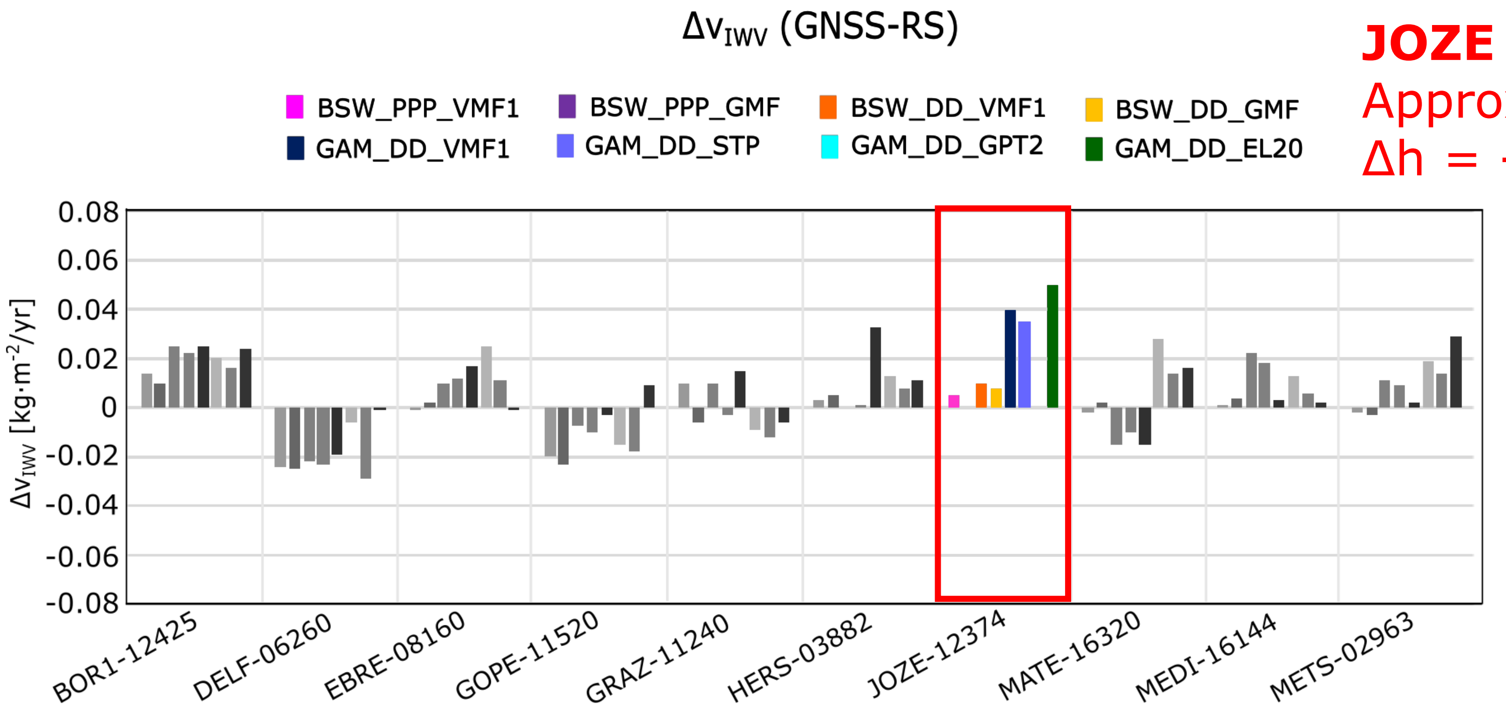
Results – IWV linear trend



HERS - 03882
Approx. dist. ~4 km
Δh = -21 m

GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
HERS	03882	0.003	0.005	0.000	0.001	0.033	0.013	0.008	0.011

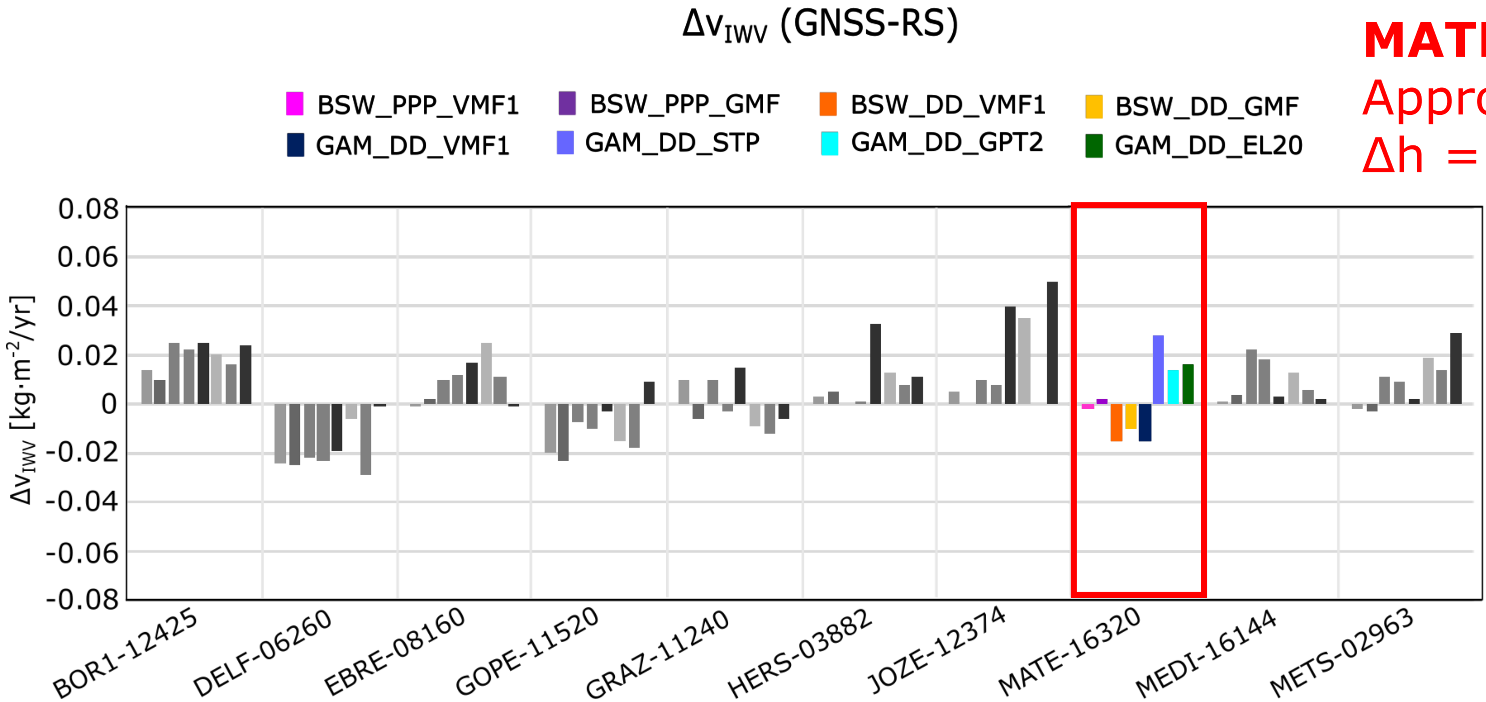
Results – IWV linear trend



JOZE - 12374
Approx. dist. ~34 km
Δh = -14 m

GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
JOZE	12374	0.005	0.000	0.010	0.008	0.040	0.035	0.000	0.050

Results – IWV linear trend



MATE - 16320
Approx. dist. ~110km
Δh = 480 m

GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
MATE	16320	-0.002	0.002	-0.015	-0.010	-0.015	0.028	0.014	0.016

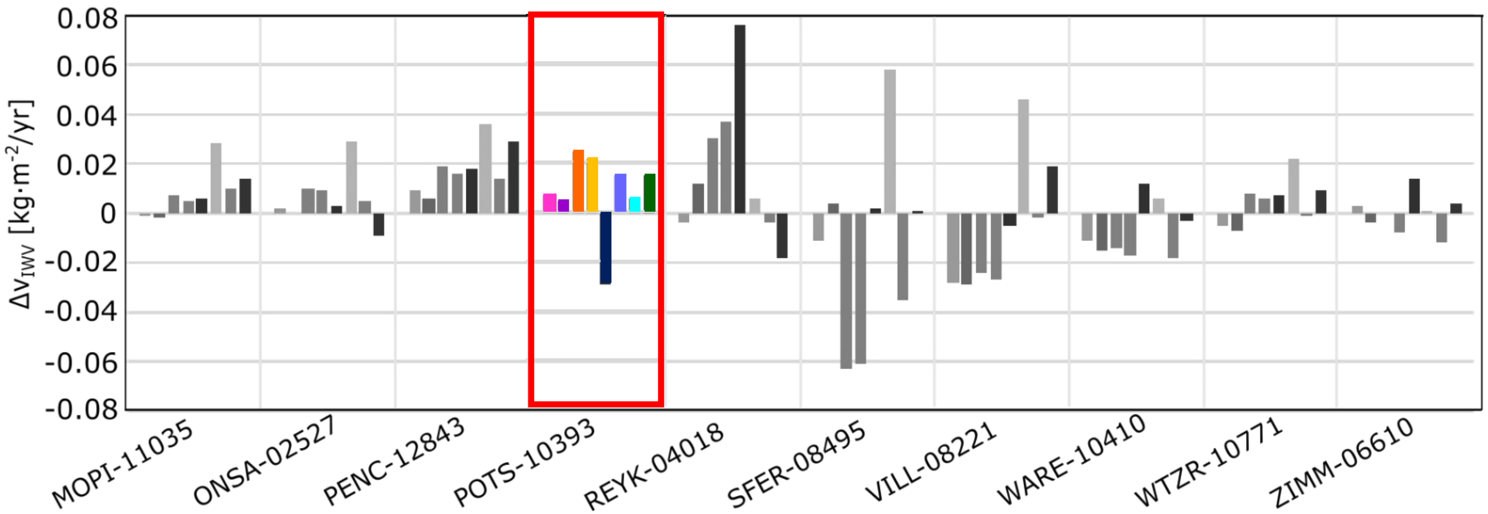
Results – IWV linear trend

Δv_{IWV} (GNSS-RS)

BSW_PPP_VMF1 BSW_PPP_GMF BSW_DD_VMF1 BSW_DD_GMF
GAM_DD_VMF1 GAM_DD_STP GAM_DD_GPT2 GAM_DD_EL20

POTS - 10393
Approx. dist. ~74 km
Δh = -11 m

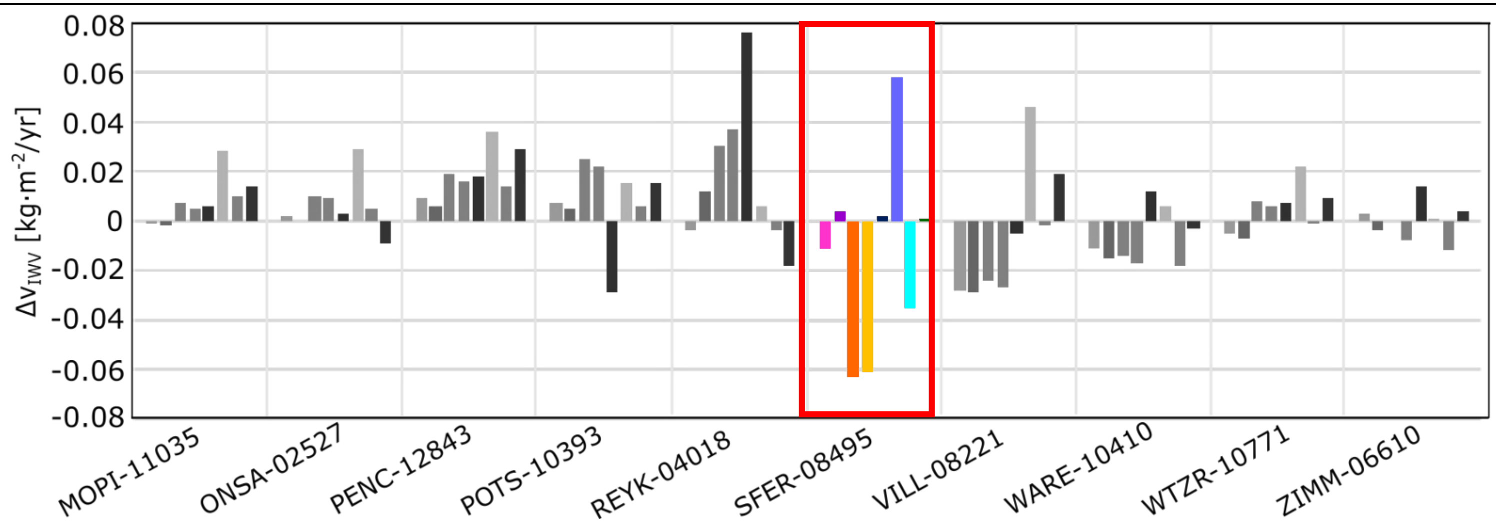
GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
POTS	10393	0.007	0.005	0.025	0.022	-0.029	0.015	0.006	0.015



Results – IWV linear trend

SFER - 08495
Approx. dist. ~84 km
Δh = 36 m

GNSS station	RS station	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
		BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
SFER	08495	-0.011	0.004	-0.063	-0.061	0.002	0.058	-0.035	0.001



Results – IWV linear trend

- Similar results for both PPP solutions (abs. mean = 0.005 kg m^{-2}/year)
- For PPP solutions:
  - ✓ 16/20 stations have $|\Delta v_{IWV}| \leq 0.01$ kg m^{-2} / year.
  - ✓ Only 3 station (DELF, GOPE, VILL) $|\Delta v_{IWV}| \geq 0.02$ kg m^{-2} / year

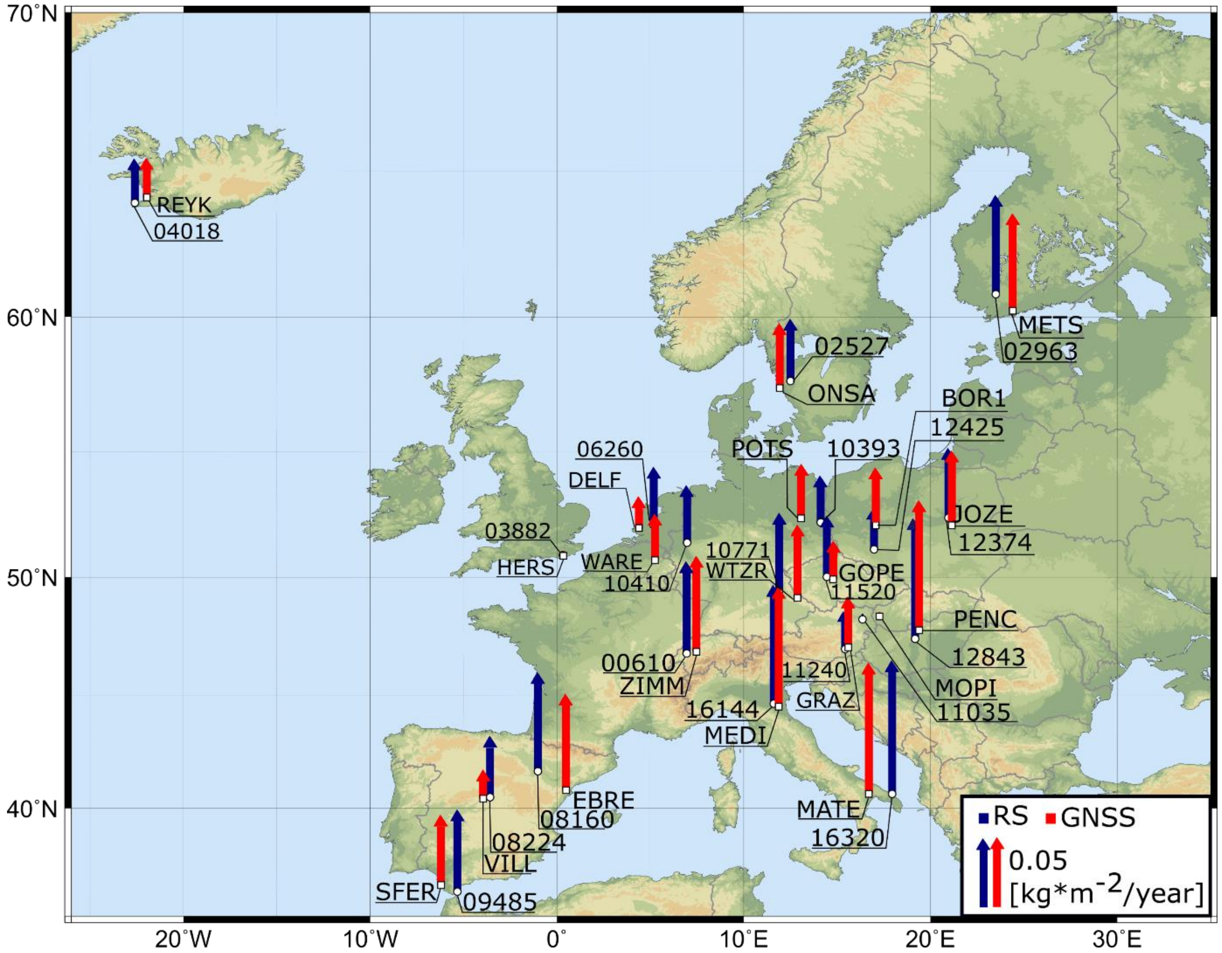
	$\lvert\Delta v_{IWV}\rvert \leq 0.01$ kg m^{-2} / year	$\lvert\Delta v_{IWV}\rvert \geq 0.02$ kg m^{-2} / year
BSW_DD_VMF	**9**	**7**
BSW_DD_GMF	**9**	**6**
GAM_DD_VMF	**8**	**5**
GAM_DD_STP	**5**	**10**
GAM_DD_GPT2	**9**	**2**
GAM_DD_EL20	**10**	**4**

Results – IWV linear trend

	Δv_{IWV} [kg m^{-2} / year] (GNSS – RS)							
	BSW_PPP_VMF	BSW_PPP_GMF	BSW_DD_VMF	BSW_DD_GMF	GAM_DD_VMF	GAM_DD_STP	GAM_DD_GPT2	GAM_DD_EL20
Max.	-0.028	-0.029	-0.063	-0.061	0.076	0.046	-0.035	0.050
Abs. mean	0.008	0.008	0.017	0.016	0.017	0.022	0.012	0.014
STD	0.011	0.011	0.022	0.022	0.023	0.018	0.015	0.016

Results

- Linear trend value for RS (navy) and GNSS PPP (red) for the 01.1996-12.2015 period of time.



Conclusions

- ERA-Interim can be successfully used in ZTD to IWV conversion. Validation performed based on 20 RS stations proved that its use introduce uncertainty to the IWV linear trend at the level of 0.006 kg m^{-2}/year.
- The highest consistency between the GNSS IWV linear trends and RS IWV linear trends was found for the PPP solutions. Both in terms of using VMF1 or GMF in PPP mode estimated long term IWV changes were usually characterized by the highest accuracy.
- The highest differences between the GNSS PPP and RS were found only for these stations which are located at higher altitudes. Therefore, some altitude dependent error both for the GNSS PPP and RS method should be considered in future works.

Conclusions

- DD solutions, widely regarded as the most accurate, were characterized by lower consistency w.r.t. RS than the PPP ones. The PPP solutions are realized individually whereas the DD solutions are realized in regional network. This may indicate that due to some network effects, DD method may introduce to the troposphere solutions errors which affect the proper investigation of long term changes.
- GPT2 brings benefits to the climate related studies. This is probably due to the fact that this empirical model better represents long term tropospheric variations than numerical weather models like ECMWF, which are mostly focused on short-time forecasts.

Thank you for your attention!

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Baldysz Z., Nykiel G., Figurski M., Araszkiewicz A. (2018) *Assessment of the Impact of GNSS Processing Strategies on the Long-Term Parameters of 20 Years IWV Time Series*. Remote Sens. 10, no. 4: 496, doi:10.3390/rs10040496

Calculations were carried out at the Academic Computer Centre in Gdansk.