The homogenization of GPS Integrated Water Vapour time series: methodology and benchmarking the algorithms on synthetic datasets

R. Van Malderen[1], E. Pottiaux[2], A. Klos[3], O. Bock[4], J. Bogusz[3], B. Chimani[5], M. Elias[6], M. Gruszczynska[3], J. Guijarro[7], S. Zengin Kazancı[8] and T. Ning[9]

1 RMI

2 Royal Observatory of Belgium

3 WAT

4 IGN INSTITUT NATIONAL DE L'INFORMATION GÉOGRAPHIQUE ET FORESTIÈRE

5 ZAMG Zentralanstalt für Meteorologie und Geodynamik

6 Nem jeleníthető meg a kép. Lehet, hogy nincs elegendő memória a megnyitásához, de az sem kizárt, hogy sérült a kép. Indítsa újra a számítógépet, és nyissa meg újból a fájlt. Ha továbbra is a

7 AEMet Agencia Estatal de Meteorología

8 KARADENİZ TEKNİK ÜNİVERSİTESİ 1955

9 LANTMÄTERIET

Outline

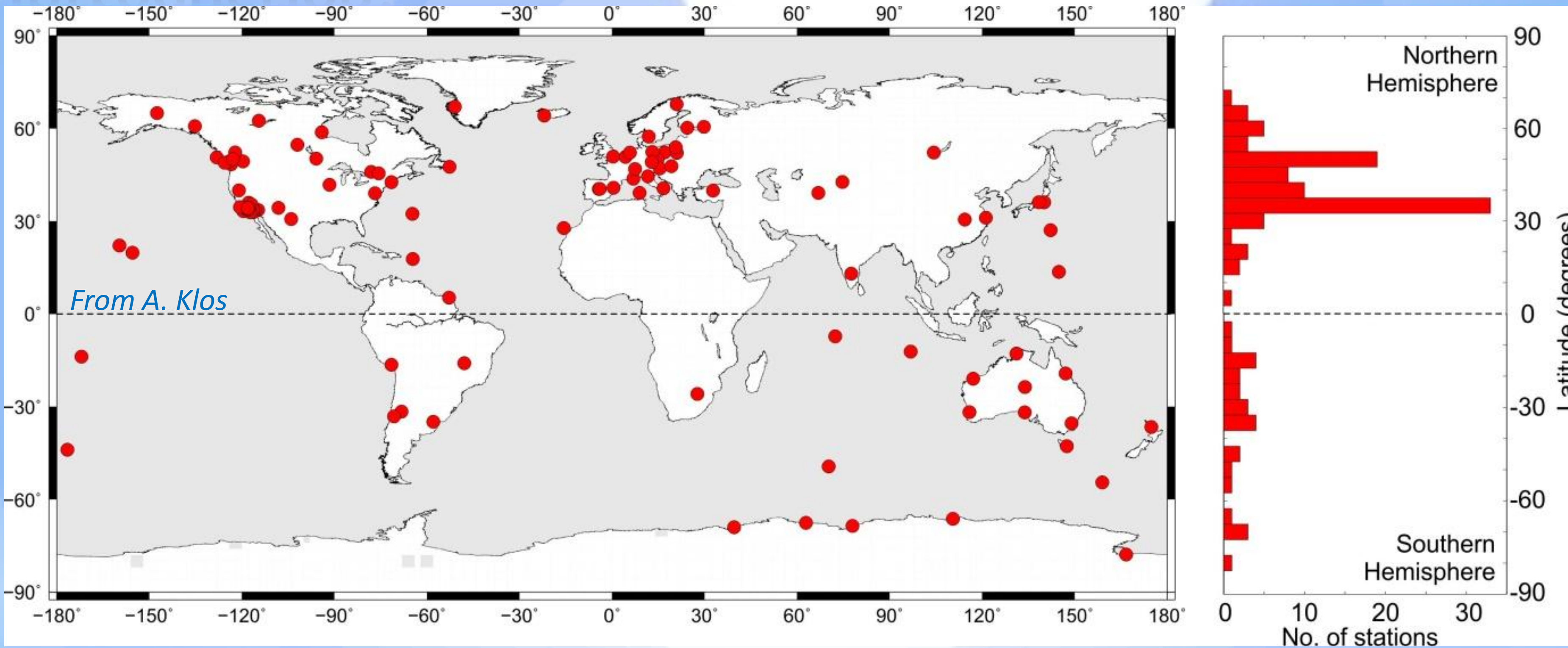
1. Motivation and introduction
2. Methodology
3. Synthetic dataset generation
4. Assessment of the performance of the homogenization tools on the synthetic dataset
5. Outlook

Motivation

- COST action GNSS4SWEC 'Advanced Global Navigation Satellite Systems tropospheric products for monitoring severe weather events and climate'
- WG3: Use of GNSS tropospheric products for climate monitoring (e.g. Integrated Water Vapour (IWV) = Precipitable Water (PW))
- From different presentations at different GNSS4SWEC workshops, it turned out that different groups were showing results from time series analyses, sometimes based on the same datasets.
- They were dealing/struggling with the homogenization of their datasets.

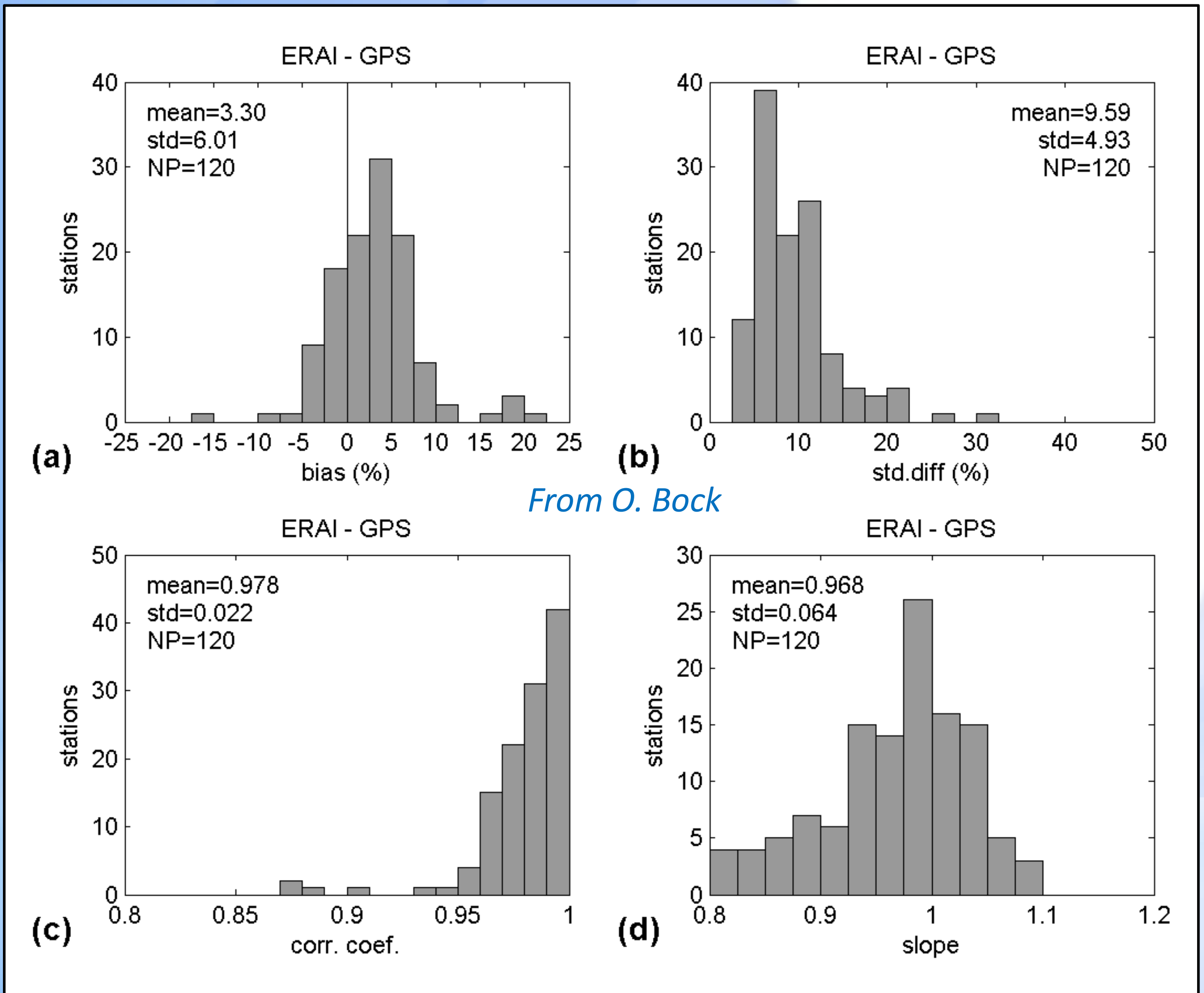
→ common activity, on a reference IWV dataset.

Introduction: the reference IWV dataset



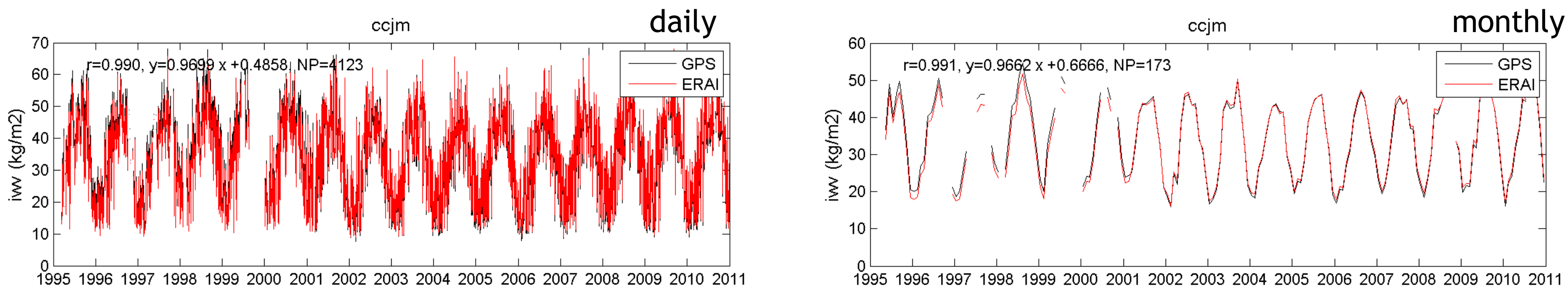
- 120 sites worldwide, with homogeneous reprocessing from 1995 – 2010
- IGS repro 1: International GNSS Service, first reprocessing
- screened, outlier removed, and ZTD converted to IWV by O. Bock

Methodology: use of a reference IWV dataset (ERA-interim)

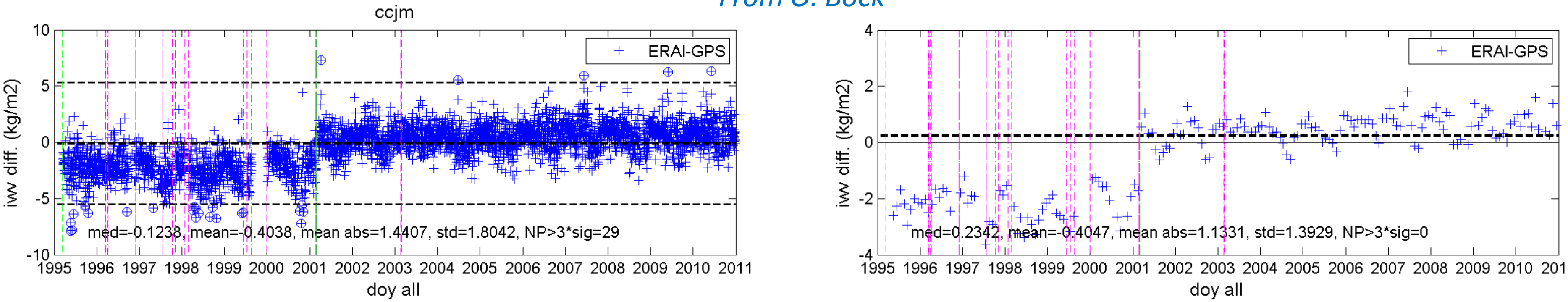


- good correlation between IGS repro 1 and ERA-interim model output
- but: not fully independent datasets
  - ✓ ERA-interim is used to screen the GPS data.
  - ✓ ERA-interim is used to convert the Zenith Total Delay from GPS to IWV (surface pressure, weighted mean temperature).
- ERA-interim not homogenous either!

Methodology: use of a reference IWV dataset (ERA-interim)



From O. Bock



➔ We will look for break points/change points in the GPS – ERA-interim IWV differences series.

Generation of synthetic dataset: how?

- based on the comparison of the epochs identified by different tools, we decided to build synthetic datasets with known inserted offsets for
  - ✓ the assessment of the performance of the different tools
  - ✓ a sensitivity analysis of this performance on the properties of the datasets

- synthetic datasets of the IWV differences,

1. based on the characteristics of the real GPS – ERA-interim IWV differences:
   - ✓ analysis of significant frequencies
   - ✓ noise model
   - ✓ linear trends
   - ✓ gaps

   computations were performed with **Maximum Likelihood Estimation** (MLE) in the Hector software (Bos et al., 2013).

2. based on the characteristics of the offsets in the real IWV differences:
   - ✓ number
   - ✓ typical amplitudes

   around 1000 epochs of instrumental changes, reported in the stations metadata, were manually checked in the IWV differences (164 confirmed + 57 new ones)
   → also used for 1st order correction of the data

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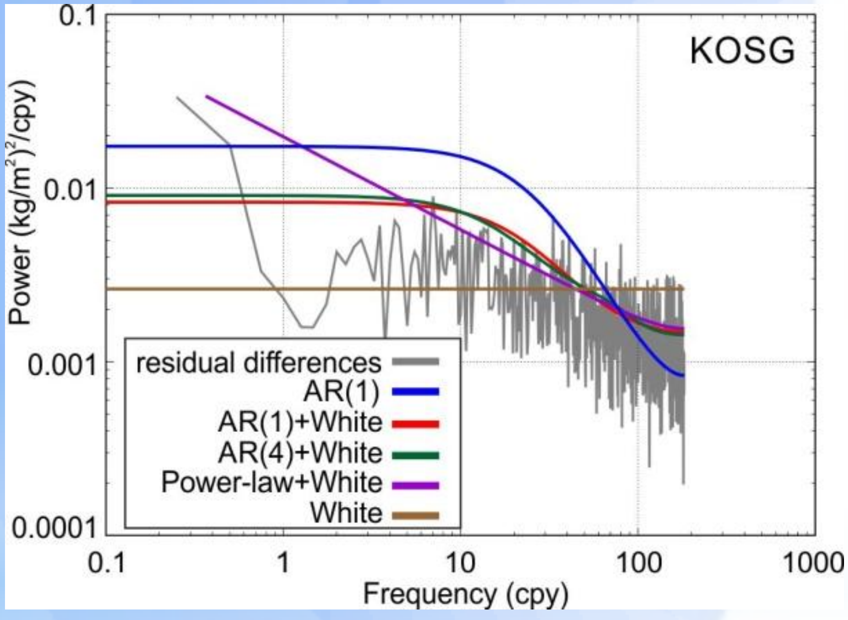
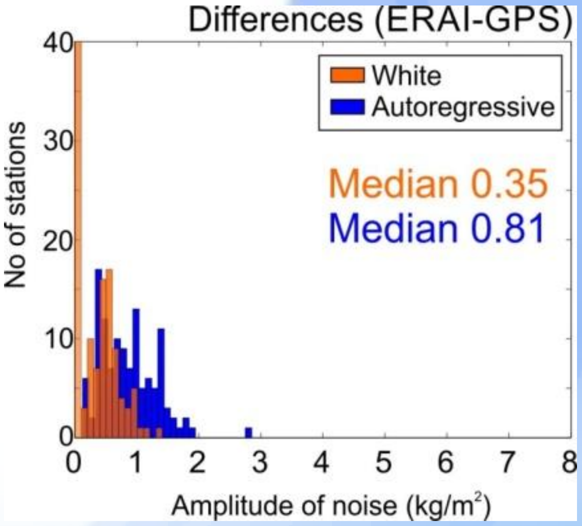
Noise model

- combination of autoregressive process of first order plus white noise (**AR(1)+WN**) characterized by: coefficient, fraction and amplitude (AR), amplitude (WN).





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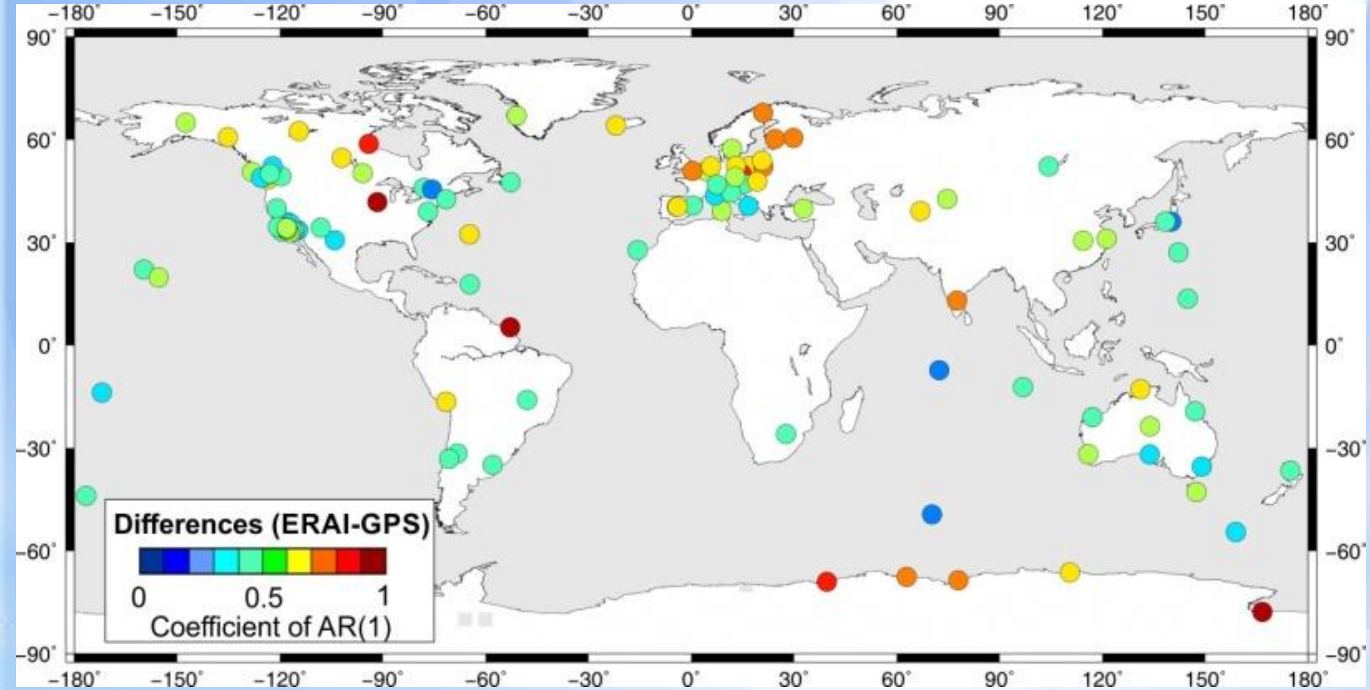
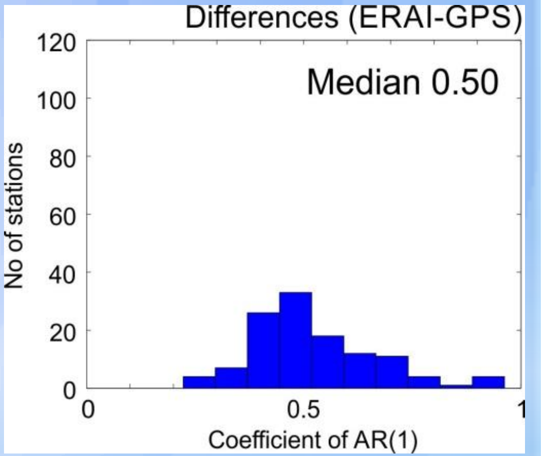
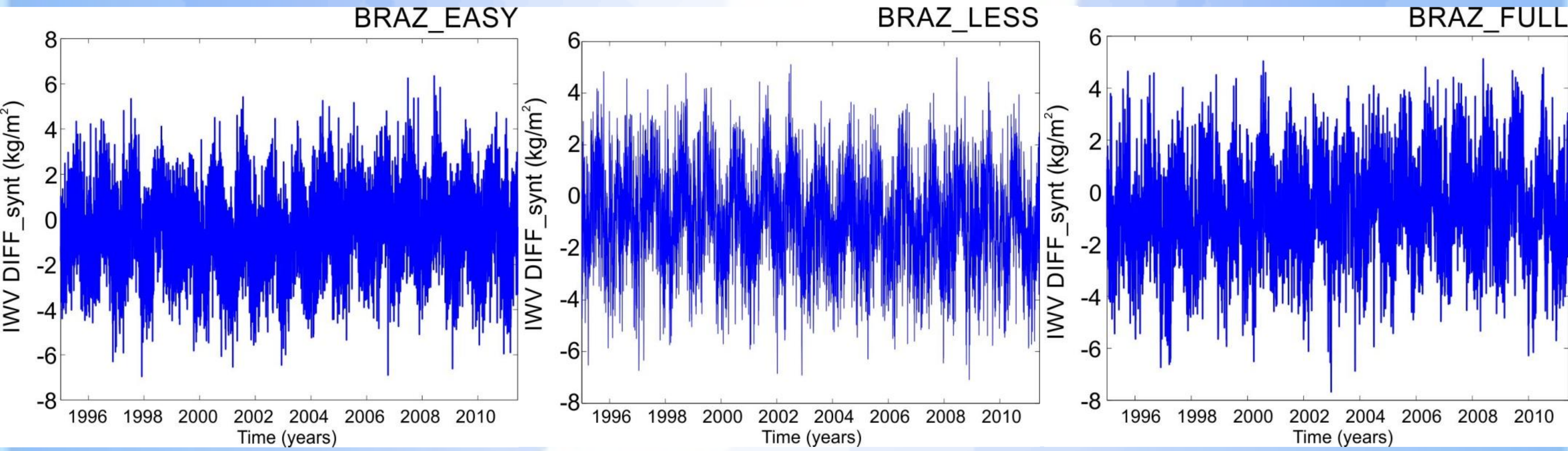




3 variants of synthetic time series of IWV differences

For every station (120 stations!), 3 variants of synthetic time series were created:

1. **'easy' dataset:** seasonal signals (annual, semi-annual, ter- and quater-annual, if present for a particular station) + offsets + white noise (WN)
2. **'less-complicated' dataset:** same as 1. + autoregressive process of the first order (noise model = AR(1)+WN)
3. **'fully-complicated' dataset:** same as 2. + trend + gaps (up to 20% of missing data = overshoot!)



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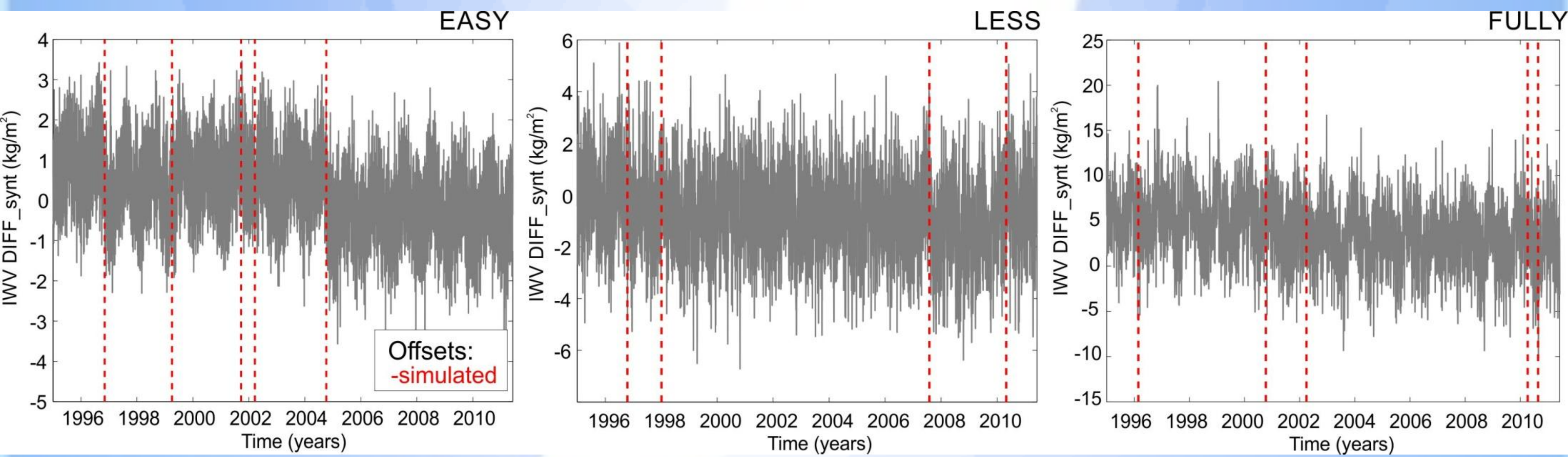

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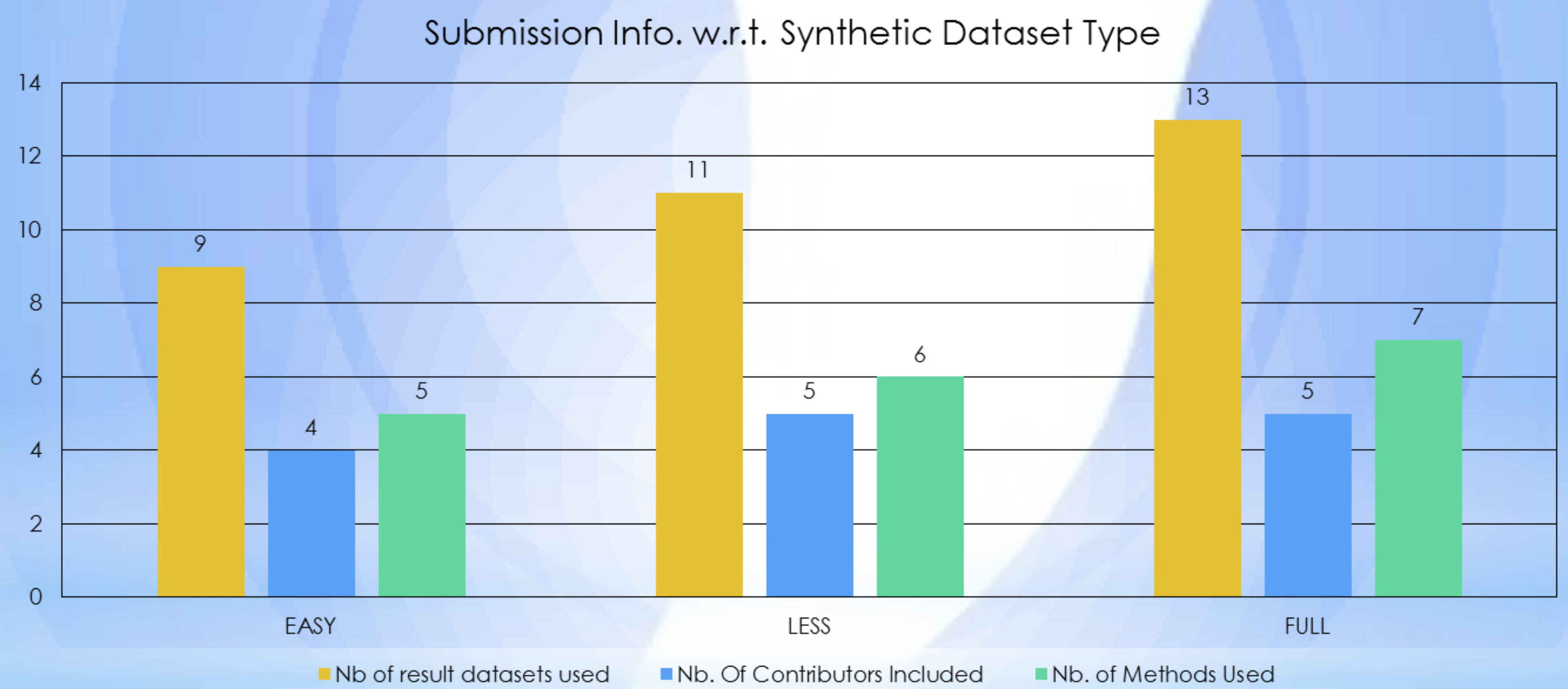
Which homogenization tools?

Climatol **J. Guijarro**	HOMOP **B. Chimani**	PMTred **T. Ning**
Non-parametric tests **R. Van Malderen**	2-sample t-test **M. Elias**	Pettitt test **S. Zengin Kazancı**

	Method 1	Method 2	Method 3	Method 4	Method 5	Method 6	Method 7
Operator	M. Elias	R. Van Malderen	R. Van Malderen	J. Guijarro	T. Ning	S. Zengin	B. Chimani
Method / SW	2-sample t-test	2 of 3	PMW	CLIMATOL	PMTred	Pettitt	HOMOP
Daily/Monthly	D+M	D+M	D+M	D+M	D+M	D	X
Easy/Less/Full	E+L+F	E+L+F	E+L+F	L+F	E+L+F	E+L+F	E+F

Which homogenization tools?



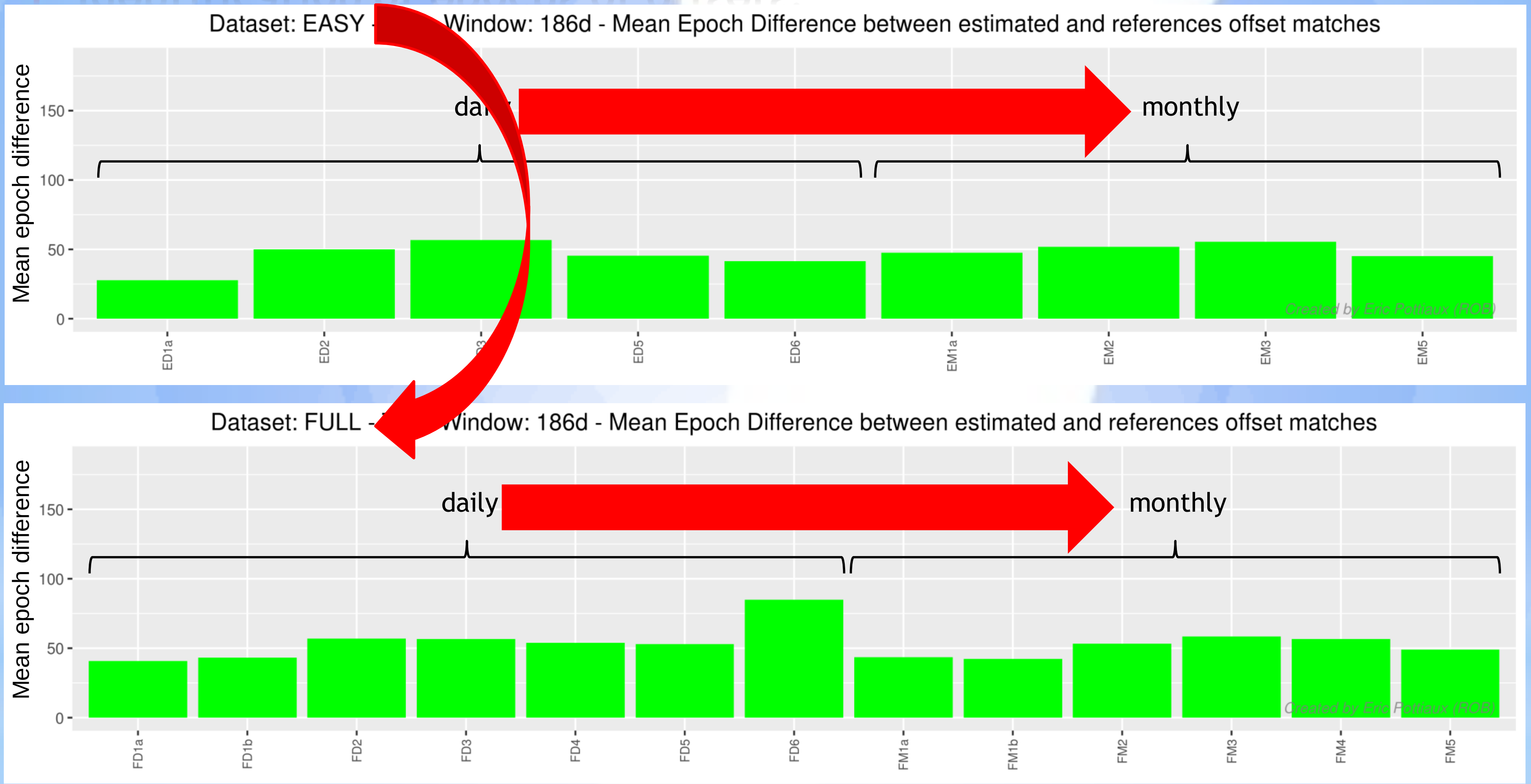
Assessment of the performance of tools on…

1. … the identification of the **epochs** of the inserted breakpoints (+ sensitivity analysis) in the synthetic datasets.
2. … the estimation of the **trends** that were or were not imposed to the 3 sets of synthetic IWV differences.

→ *Venema et al. 2012, Benchmarking homogenization algorithms for monthly data, Climate of the Past, 8, 89-115, doi:10.5194/cp-8-89-2012.*

→ *Gazeaux et al. 2013, Detecting offsets in GPS time series: first results from the detection of offsets in GPS experiment, J. Geophys. Res. Solid Earth, 118, doi:10.1002/jgrb.50152.*

1. Identification of epochs of offsets: defining a proper time window



➔ In this presentation, a time window of 62d (2 months), will be assumed.

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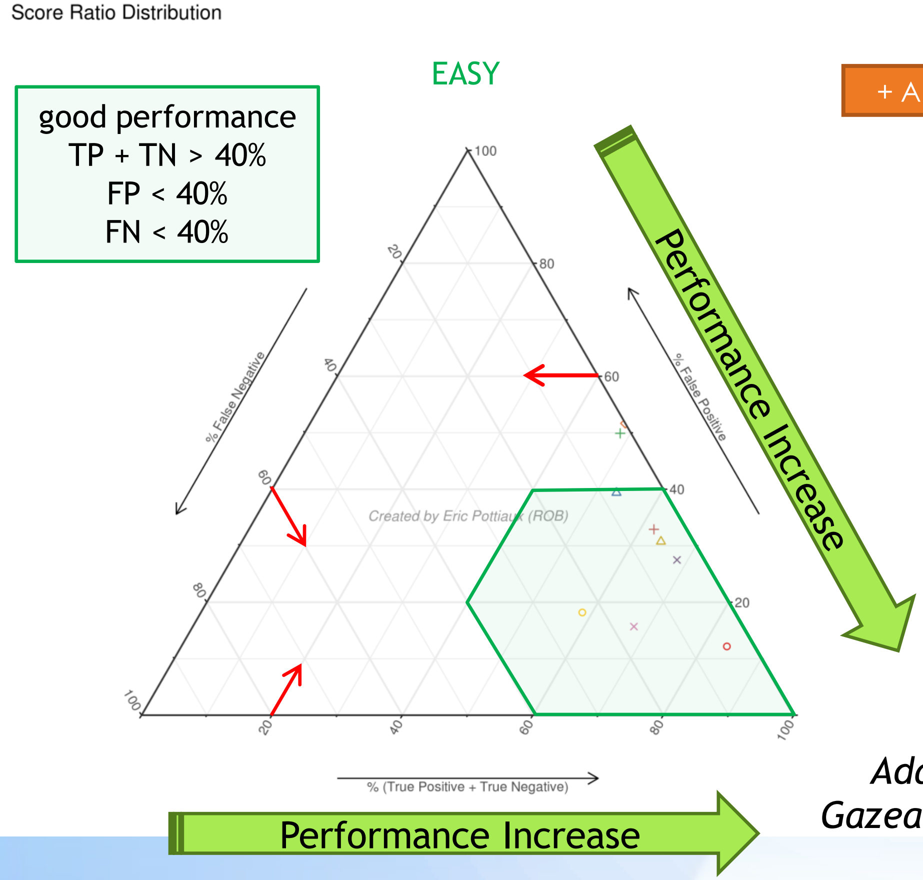
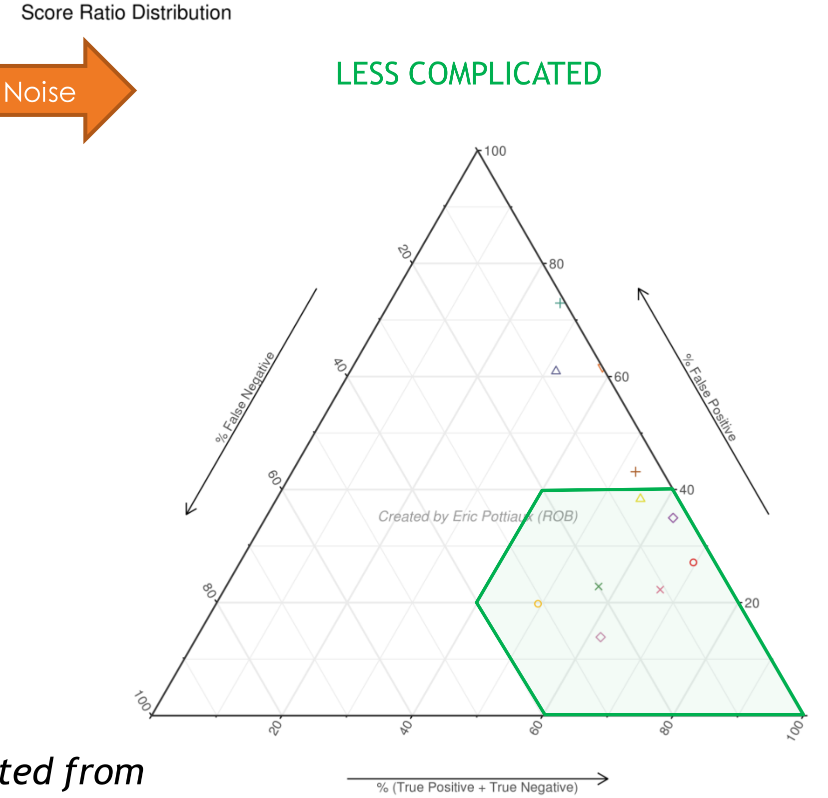
1. Identification of epochs of offsets: detection scores

good performance
TP + TN > 40%
FP < 40%
FN < 40%



+ A.R. Noise



Adapted from Gazeaux et al. 2013

➔ good performance for the majority of the tools for the easy and less complicated dataset

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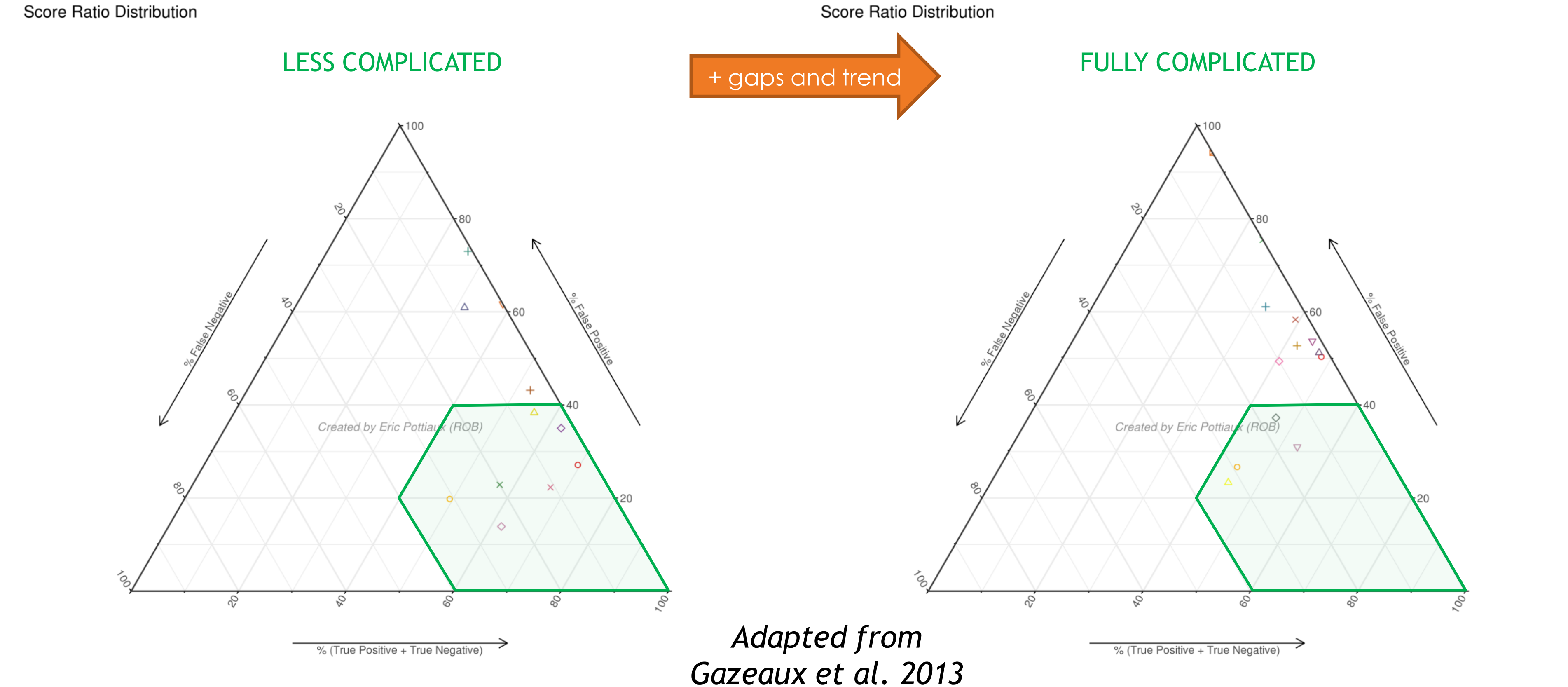
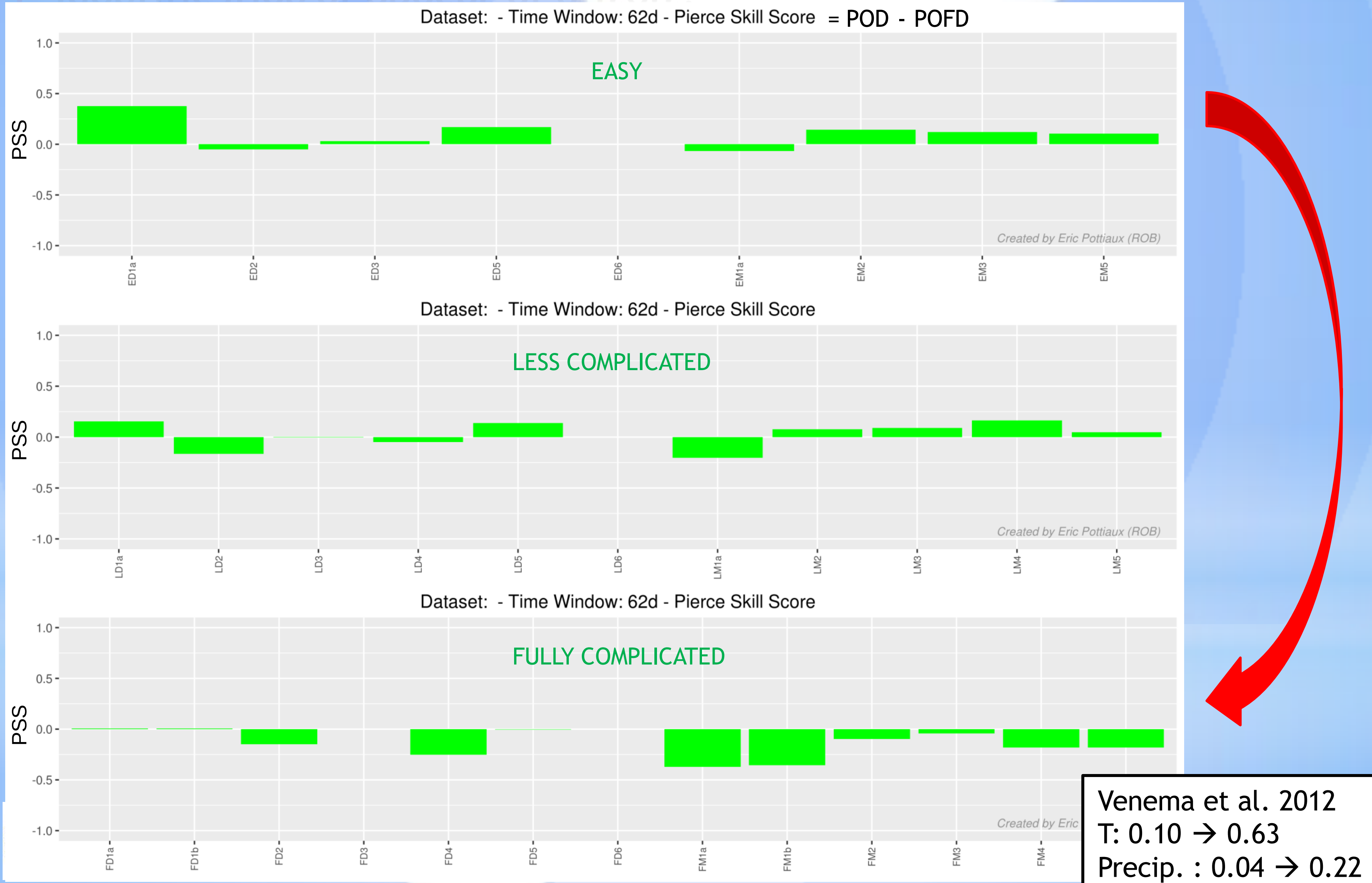
1. Identification of epochs of offsets: detection scores



Adapted from Gazeaux et al. 2013

➔ performance decreases drastically for almost all the tools when adding gaps and a trend in the benchmark time series

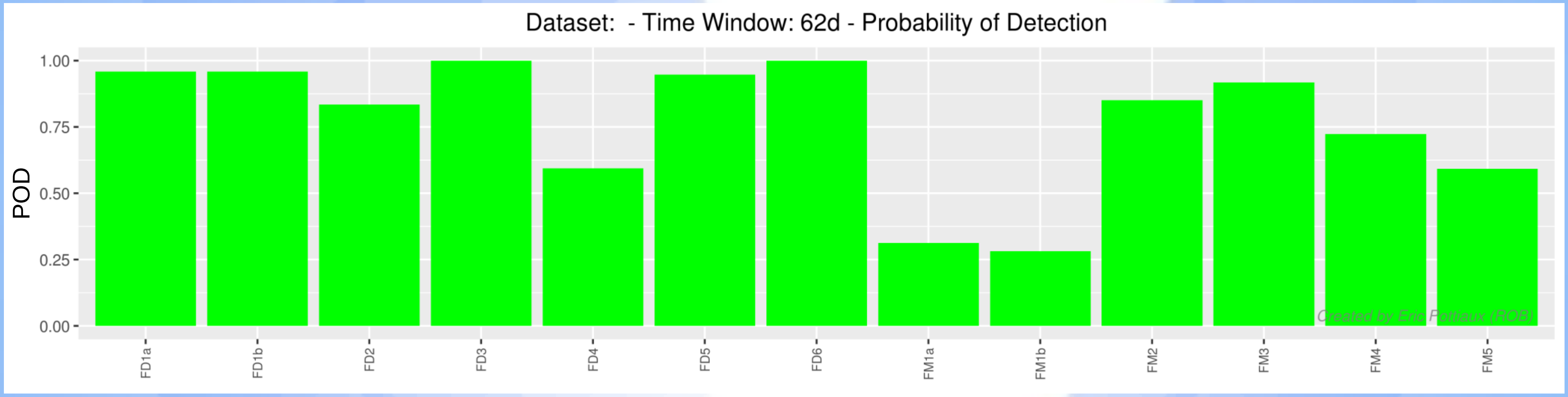
1. Identification of epochs of offsets: detection scores

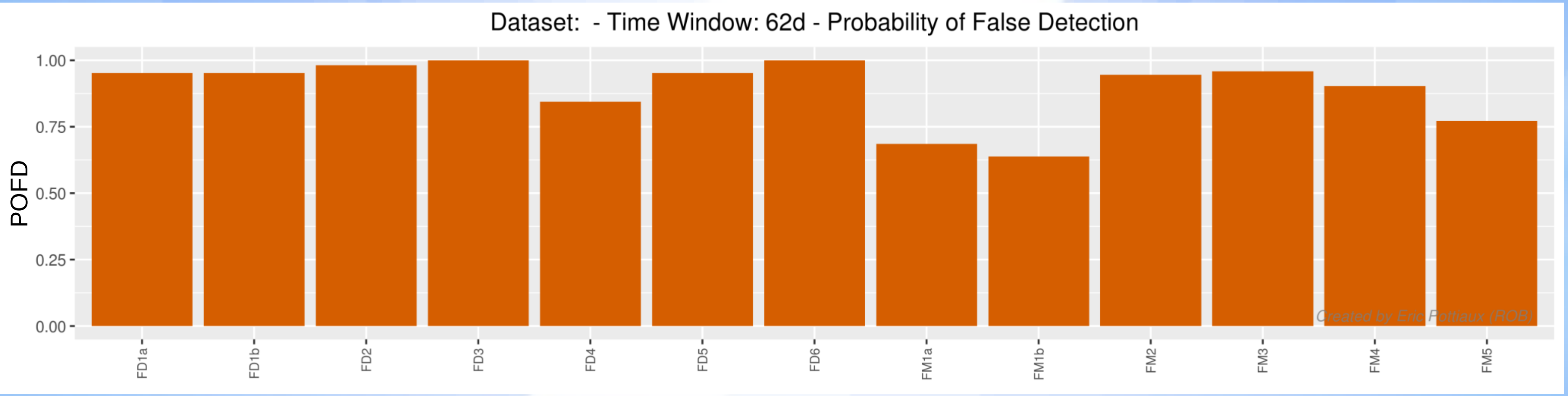


Venema et al. 2012
T: 0.10 → 0.63
Precip. : 0.04 → 0.22

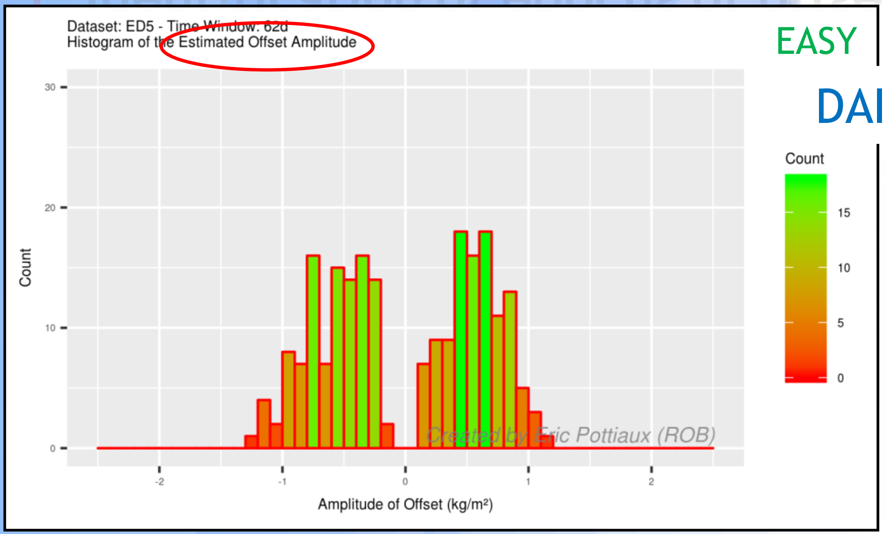
1. Identification of epochs of offsets: detection scores

FULLY COMPLICATED

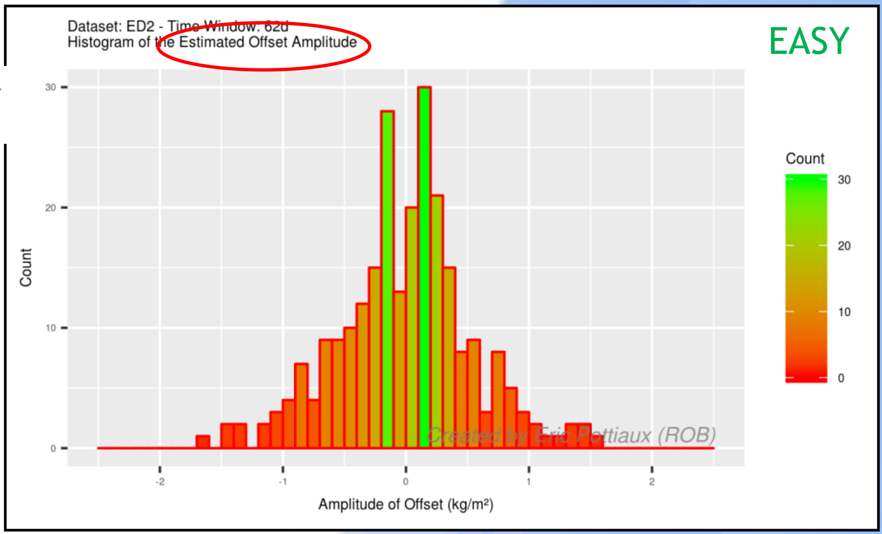


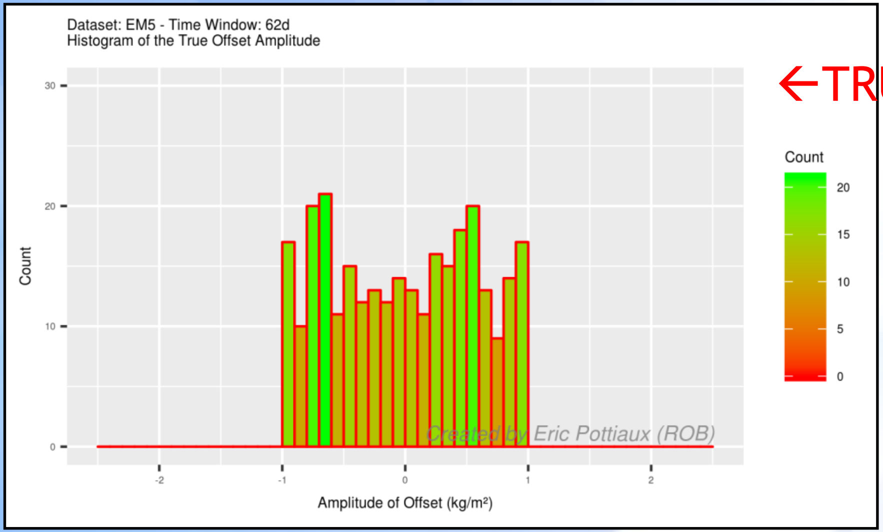


1. Identification of epochs of offsets: amplitudes of offsets

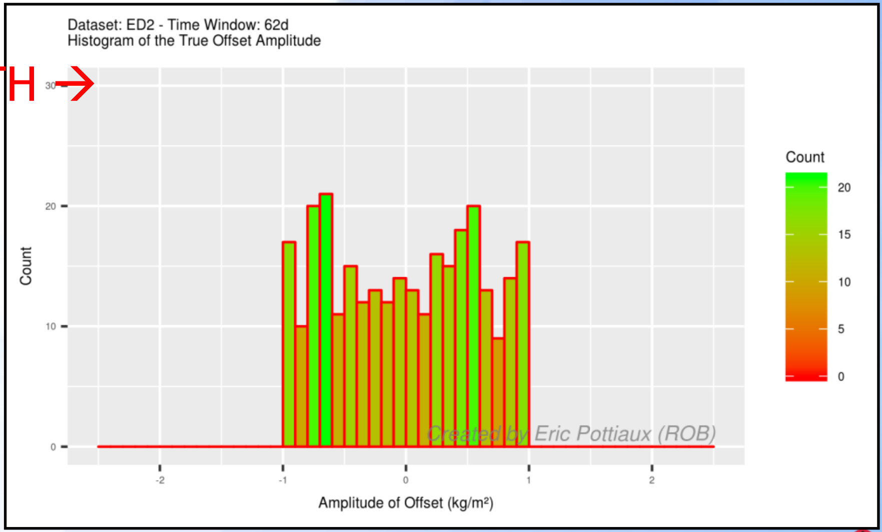


DAILY





←TRUTH→



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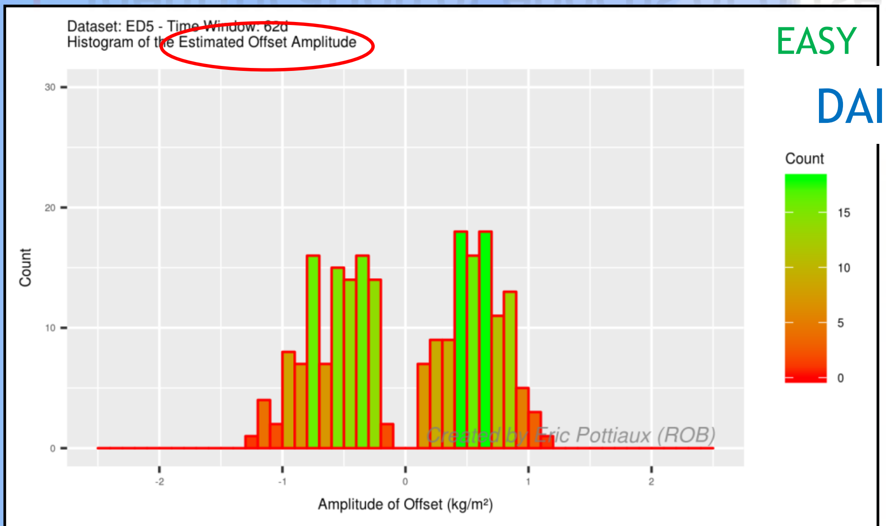
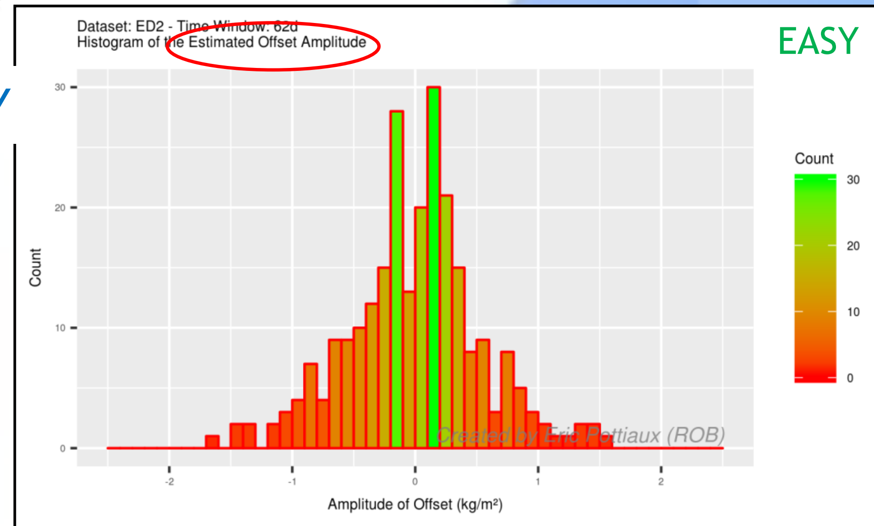
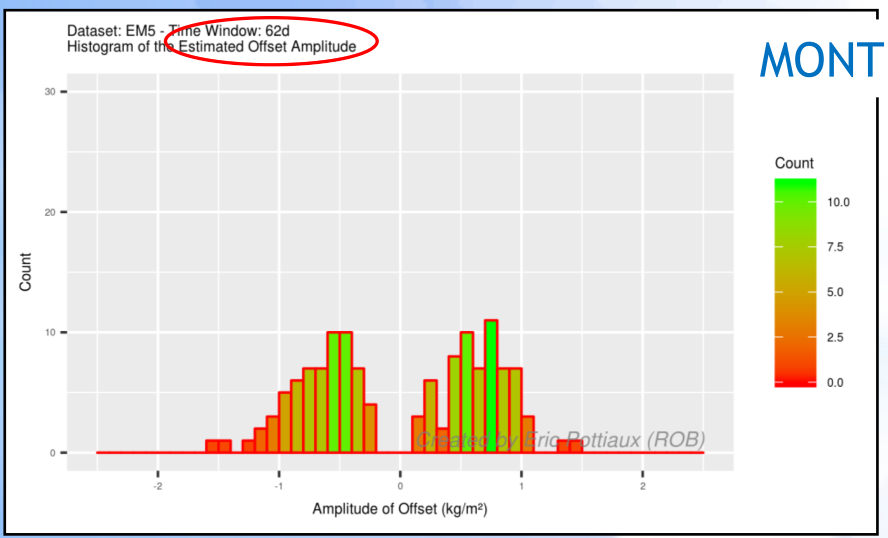
1. Identification of epochs of offsets: amplitudes of offsets

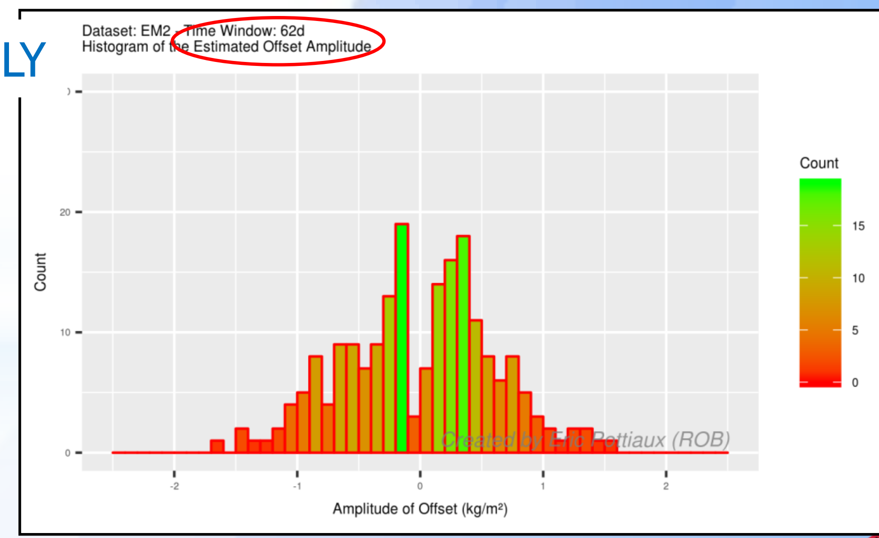
DAILY



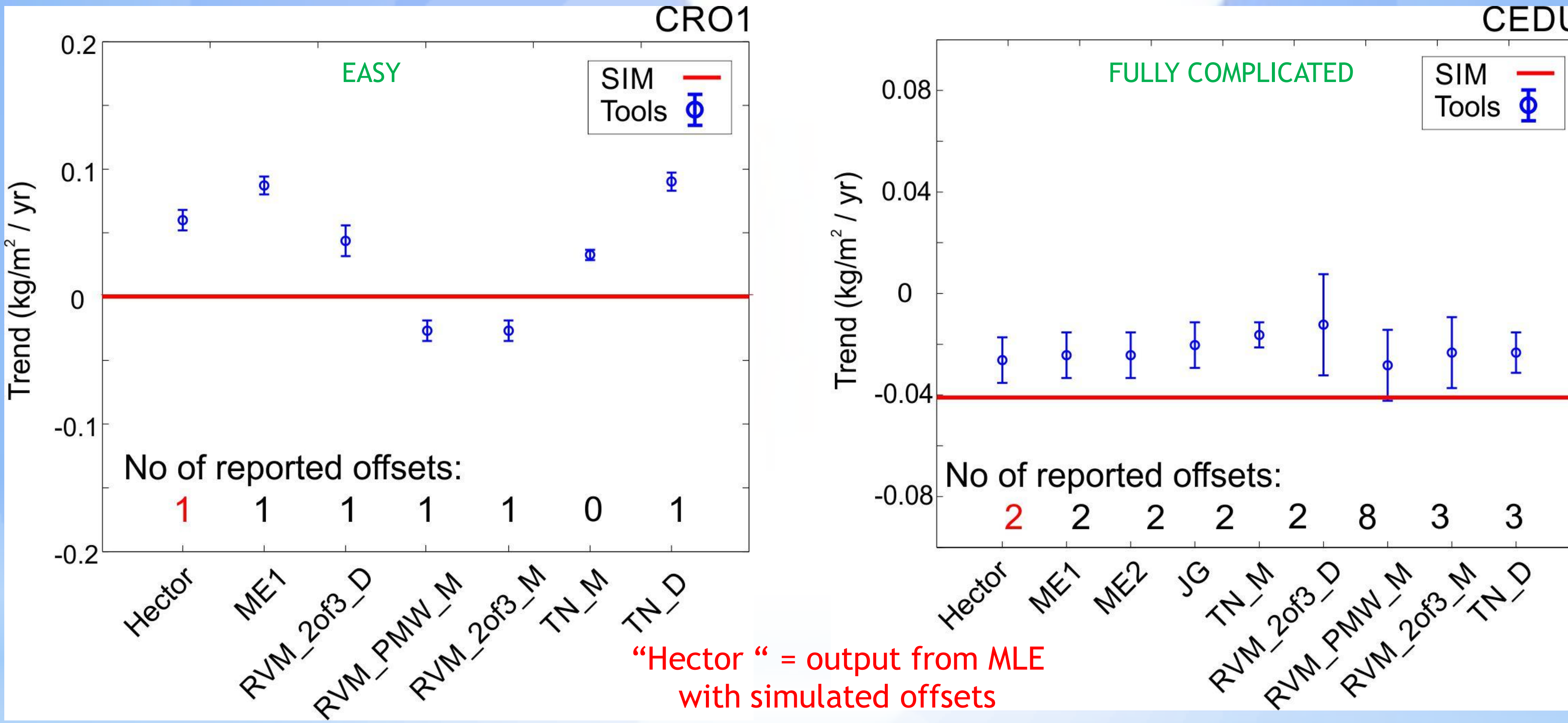


MONTHLY





2. Trend estimation



➔ large variety of trends (and uncertainties) for the different corrected time series

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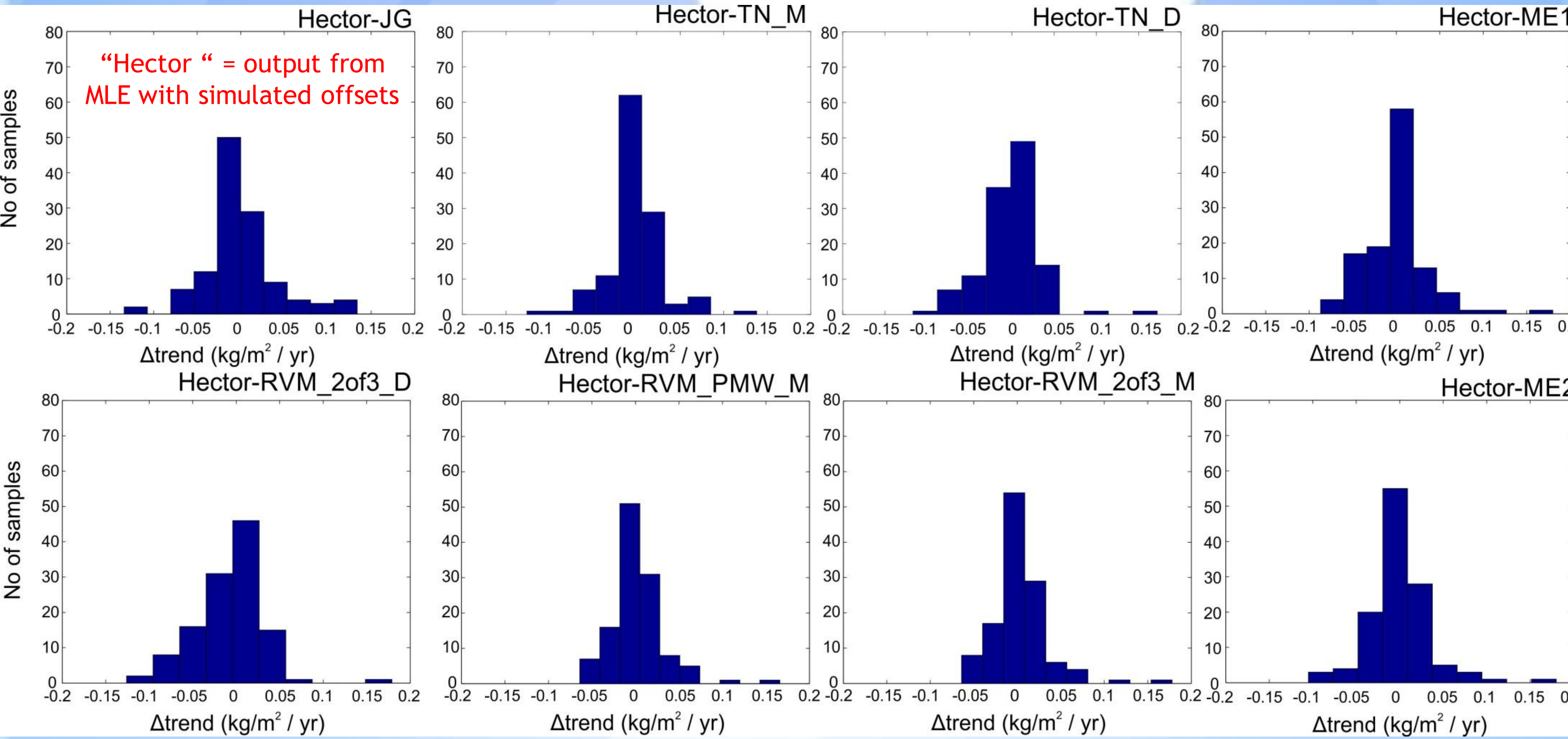
2. Trend estimation

FULLY COMPLICATED



➔ most trends differ within ±0.05 mm/yr.

Workplan

- more detailed assessment of the performance of the different tools (and sensitivity analysis): CRMSE, …
- The epochs and amplitudes (and feedback) of the offsets in the synthetic datasets is given to the participants who already provided their solutions → fine-tuning of their tools
- We highly welcome other contributions (tools, solutions) in our activity! Interested? Please contact me at roeland@meteo.be.
- A next generation of a fully complicated synthetic dataset will be generated:
  - ✓ fully complicated II?
  - ✓ gaps decoupled from trend(s)?
  - ✓ based on the difference of the synthetic IGS repro 1 minus the real ERA-interim?
- A second round of blind homogenization on this next generation dataset(s) will end in September.

Outlook

- application of the good performing tools on the IGS repro 1
- define a common strategy to correct the IGS repro 1 dataset, based on criteria as (examples!):
  - ✓ break points should be detected by a minimum of homogenization tools.
  - ✓ break point should be present in the metadata file of the station.
  - ✓ the amplitude of the offset should be above a certain limit.
  - ✓ break points should be detected in other IWV differences time series (e.g. IGS minus NCEPNCAR reanalysis)
- Thereafter, the focus will be on a GNSS IWV dataset centred above Europe, homogeneously reprocessed, with about 100 sites (out of 280) with data from 1996-2014 (→ neighbour-based approach possible?)
- We are looking forward to getting feedback/input/participation from your community!

Thank you for your attention

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	Ning	Elias		Van Malderen et al.		Bock et al.	KTU (Tanır Kay	Klos et al.	
	monthly	monthly	daily	monthly	daily	daily	daily	manual	
albh				15/10/2002	15/10/2002	2/05/1998	18/05/2002		
albh				15/03/2000		9/07/1998			
albh					15/02/2006	2/07/2000			
albh						12/03/2001			
albh						18/01/2005			
algo						7/02/2008	17/05/1997	12/10/2007	1
alic			20/04/2006	15/04/2006	15/04/2006	21/08/1999	26/10/2008	31/07/1999	1
alic				15/08/1999	15/08/1999	20/04/2006		15/06/2003	1
alic								6/05/2010	1
alic								11/10/1999	3
ankr	15/09/2000	15/10/2001	15/10/2001	15/10/2001	15/10/2001	3/01/2001	18/05/2005	7/02/1996	1
ankr				15/08/2000	15/09/2000	11/05/2008		23/07/1996	1
ankr				15/09/2008	15/09/2008			24/07/1997	1
ankr								16/09/1998	1
ankr								4/07/2000	1
ankr								24/11/2000	1
ankr								6/05/2008	1
ankr								4/06/1999	3
ankr								16/09/2000	3
ankr								26/11/2007	3

- breakpoints detected in metadata & visual inspection, but not by any of the groups?
- breakpoints detected by a number (all) tools, but no metadata information?
- time window! When are breakpoints coincident?

$$IWV(t_i) = a + b \cdot (t_i - t_0) + c \cdot \sin(2\pi \cdot (t_i - t_0)) + d \cdot \cos(2\pi \cdot (t_i - t_0)) +$$
$$+ e \cdot \sin(4\pi \cdot (t_i - t_0)) + f \cdot \cos(4\pi \cdot (t_i - t_0)) +$$
$$+ g \cdot \sin(6\pi \cdot (t_i - t_0)) + h \cdot \cos(6\pi \cdot (t_i - t_0)) +$$
$$+ i \cdot \sin(8\pi \cdot (t_i - t_0)) + j \cdot \cos(8\pi \cdot (t_i - t_0)) +$$
$$+ \sum_{j=1}^{n} d_j H + \varepsilon_{IWV_i}$$

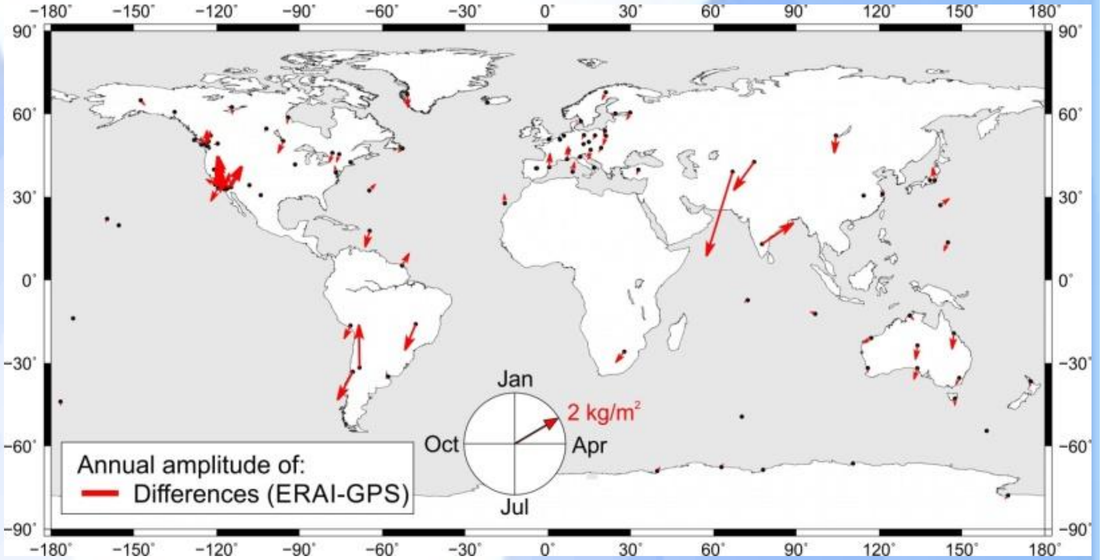
If significant frequencies were not accounted for, it may lead to wrong trend estimates.

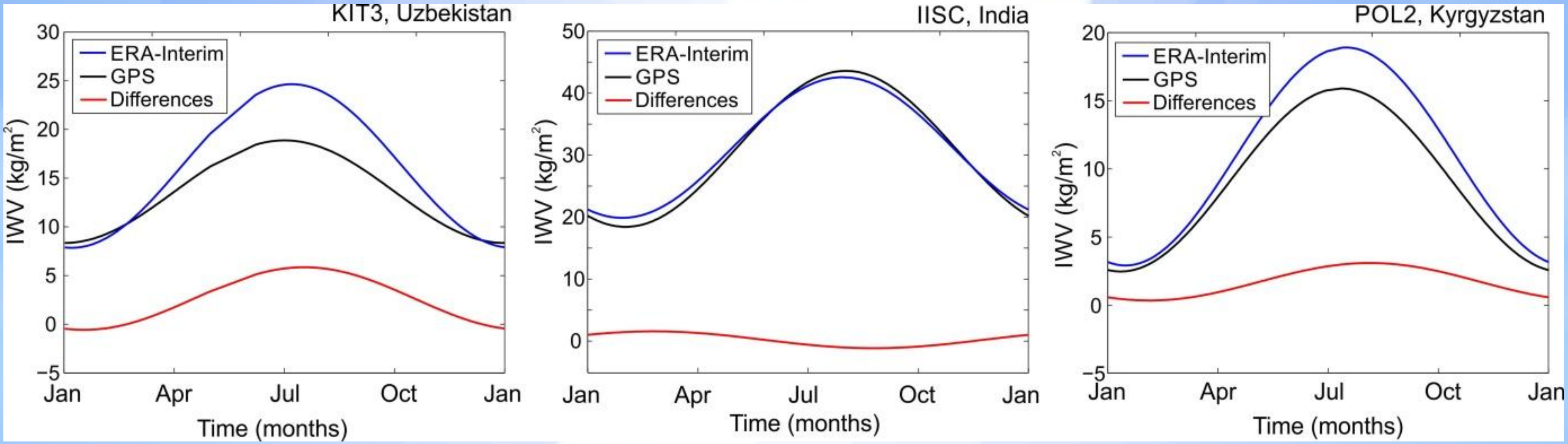
Computations were performed with Maximum Likelihood Estimation (MLE) in the Hector software.

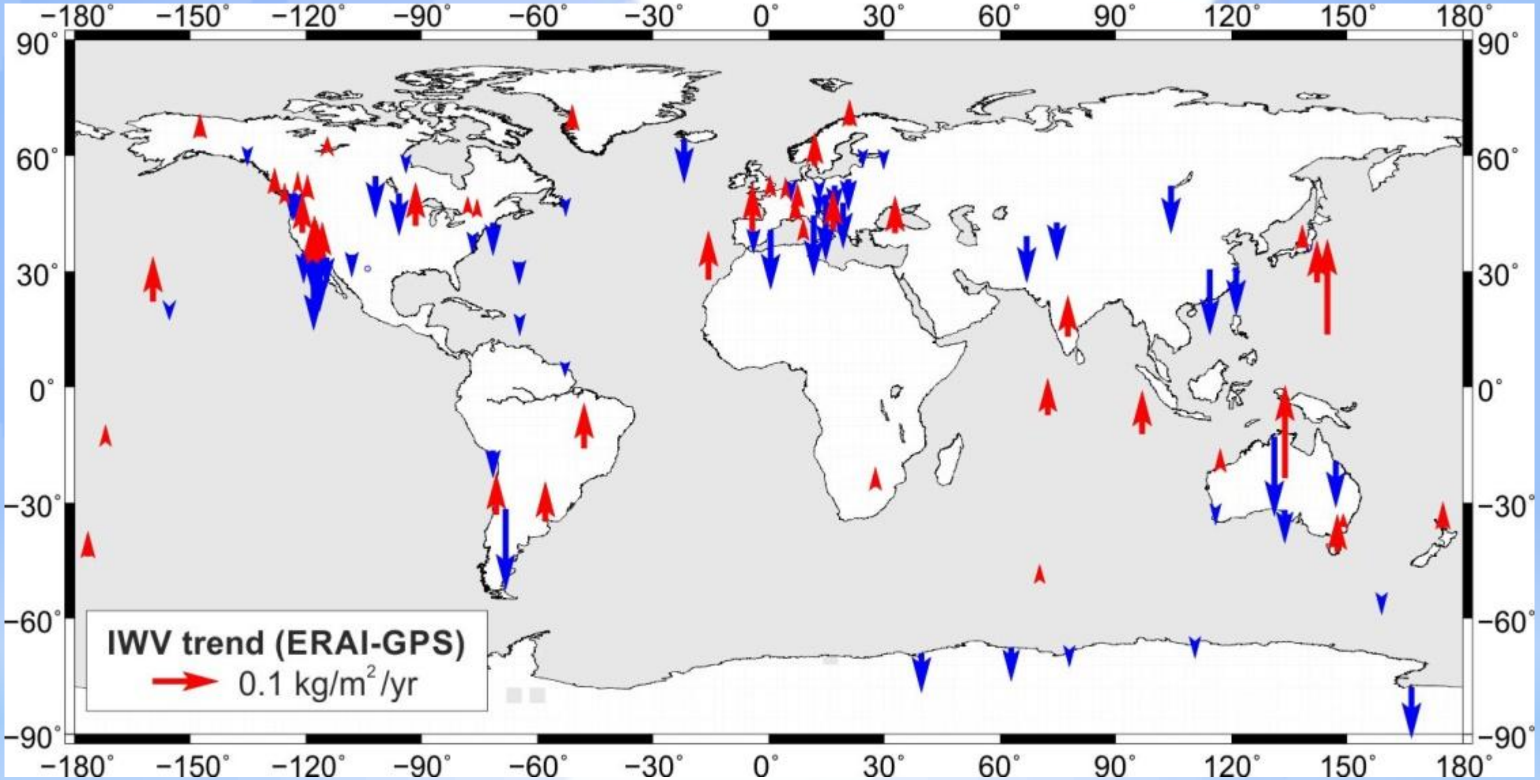
Characterization of real data:

Annual signal.

The largest differences between seasonal curves were found for KIT3, IISC and POL2 due to a shift in phase.







IWV trend (ERAI-GPS)
0.1 kg/m²/yr

Why did we go for synthetic differences (DIFF_synt)?

We examined **ERAI_synt-GPS_synt** and we couldn't have covered some part of power…

There is remaining unmodelled "signals and noise" in the time series of the real differences.