wL | delft hydraulics

Extreme still water levels

Sofia Caires[1], Ferdinand Diermanse[1], Douwe Dillingh[2] and Reimer de Graaff[1]

[1]WL|Delft Hydraulics, The Netherlands.
[2]National Institute for Coastal and Marine Management (RIKZ), The Netherlands

Motivating reference: Dillingh, D., L. de Haan, R. Helmers, G.P. Können and J. van Malde, 1993: Design water levels for the Dutch coast; statistical study (In Dutch). Rijkswaterstaat, Dienst Getijdenwateren /RIKZ, Report DGW-93.023.

WL | delft hydraulics

Motivation

Estimates of extremes of the still water level are required for the design of coastal structures. Especially in shallow regions, where waves are depth limited, the still water level being thus crucial for the determination of the wave loads.

As with all other metocean variables the determination of still water level extremes is plagued by inhomogeneity, sparsity and scarcity of the data. Moreover, it is not clear which approach is the most appropriate for estimating the extremes.

The following approaches are currently used:

1. Extreme value analysis of the SWLs.
2. Estimation of extreme water levels from the convolution of the extremal distribution of the surge (or that of a non synchronous difference between SWL and tide) with the empirical distribution of tidal levels.
3. Estimation of extreme surge levels from extreme weather conditions (winds and atmospheric pressures) and computation of pessimistic or conservative SWL estimates by adding the Highest Astronomical Tide to them.

Objectives

To assess approaches 1. and 2.

- Provide guidelines as to which should be used in a given situation.
- Using the results of our analyses with Approach 2., we shall also provide indications about the tidal level that should be used in Approach 3.
- Furthermore, in each of the approaches, two different extreme value analysis methods will be considered: the peaks-over-threshold and annual maxima methods.

Methodology in brief

Approach 1 -> Extreme value analysis of SWL data
Approach 2 -> Extreme value analysis of surge + convolution with the empirical distribution of the tide

Extreme value analysis

a) **POT/GPD**
- **POT data collection for different thresholds (with declustering)**
- **Choice of threshold on the basis of the threshold stability property**

b) **AM/GEV**
- **AM data collection**

Estimation -> **Maximum likelihood method to estimate the parameters**

Confidence intervals -> **Confidence intervals obtained using the adjusted percentile bootstrap method**

Conclusions

- There is a striking agreement between the return value point estimates provided by the different methods.
- The wider confidence intervals are those for estimates using the AM/GEV model. This is to be expected and should be more noticeable with datasets smaller than the one considered here.
- The use of Approach 2. does not result in shorter confidence intervals. This goes against the idea that not using the known tidal information is data wasteful. It could be explained from the fact that the uncertainty in the estimates is due to the rare extreme events and not the well determined tide.
- As expected, the relative amplitude of the confidence intervals increases with the return period. This sets limitations to the actual use in practice of the ‘more extreme’ return value estimates computed from a dataset with a given length.
- For the return periods longer than 10 years, the return value estimates of the convolution are equal to those of the associated surge analysis plus a constant. This constant is close to MHW.

Recommendations

- The POT/GPD approach is generally preferable to the AM/GEV approach since the estimates of the latter have greater variability, even with long datasets.
- Approach 2. does not seem to be superior, in terms of reduction of uncertainty of estimates, to Approach 1. It is therefore preferable to use Approach 1. since this is simpler and/or does not require the determination of the tidal signal. In the case of the POT/GPD approach, this of course assumes that the threshold has been taken high enough so as to exclude peaks with no surge component.
- The choice of the offset to be used in Approach 2. should take into consideration the characteristics of the basin under study. For the North Sea, the basin of the example used here, the instantaneous offset between the astronomical tide and the SWL should not be used since the two may be correlated. For other basins, such as for instance the Mediterranean Sea, where water depths are rather high, slopes are steep and the wind set-up less important, the instantaneous offset can in principle be used.
- In Approach 3., the tidal level that should be added to the water level associated with extreme weather conditions should be somewhere between Mean High Waters and Mean High Water Spring.

Extreme value theory

The extremal types theorem is the analogue of the central limit theorem for the extreme values in a sample:

- **central limit theorem -> The *mean* of a large number of random variables is *distributed approximately* according to a Gaussian distribution**
- **extremal types theorem->The *maximum* of a process over n time units of observation (e.g. nr. obs. in a year ->annual maxima) is *distributed approximately* according to a Generalized extreme value (GEV) distribution:**

$$G(z) = \exp\left\{-\left[1+\xi\left(\frac{z-\mu}{\sigma}\right)\right]^{-1/\xi}\right\}$$

, where μ, σ and ξ are called the location, scale, and shape parameters.

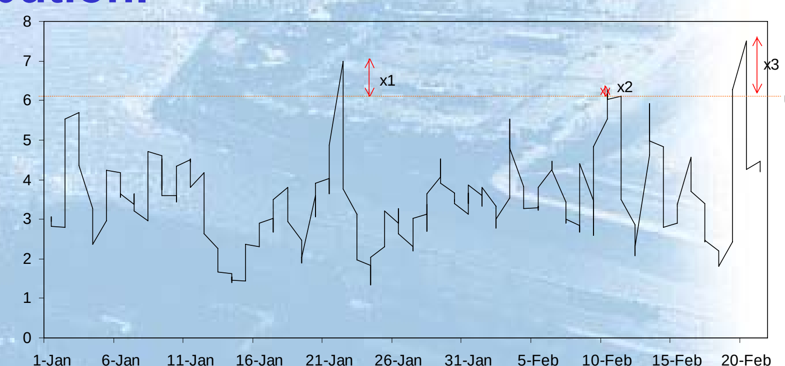
- **$\xi=0$ (type I tail) -> Gumbel distribution**
- **$\xi>0$ (type II tail, "heavier", i.e., decreases more slowly, than the type I tail) -> Fréchet distribution**
- **$\xi<0$ (type III tail , decreases more quickly than the type I tail and actually reaches 0, the domain of *z* has an upper limit) -> Weibull distribution (of maxima)**

Extreme value theory (cont)

- **If block maxima have approximately a GEV distribution, then the threshold excesses follow *approximately* a Generalized Pareto (GP) distribution.**

  I.e., peak excesses over a high threshold *u* occur according to a Poisson process with rate λ_u and are independently distributed with a Generalized Pareto Distribution.

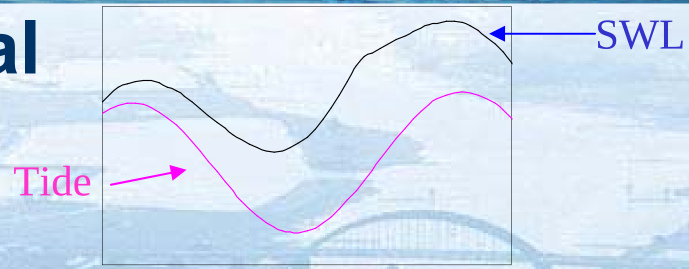
$$F_u(x) = \begin{cases} 1-(1-\xi x/\sigma)^{1/\xi} & \xi \neq 0 \\ 1-\exp(-x/\sigma) & \xi = 0 \end{cases}$$



An important property of the POT/GPD approach is the *threshold stability property*:

If a GPD is a reasonable model for the excesses over a threshold u_o,
then for a higher threshold u a GPD should also apply;
the two GPD's have identical shape parameter and their scale parameters are related.

Convolution integral



Given that the still water level (z) is the sum of the residual/surge (y) and the tide (x) and that these variables can, under certain conditions, be assumed independent, another approach for obtaining the extreme value distribution of the SWL is to estimate the distribution function of 'large values' of SWL by the convolution integral

$$F(z) = \int G_r(z-x) f(x) dx$$

where G_r is the distribution function of 'large values' of the residual (either the GPD or the GEV) and f is the (in principle fully known) density function of the tide levels.

Data description

Hoek van Holland tide gauge

High water SWL peak and tide

Data from 1887 until 2006

The Netherlands has a high safety standard

The design criteria for sea dikes varies from 1/2000 to 1/10000 years

Pre-processing of the data

Surge variable:

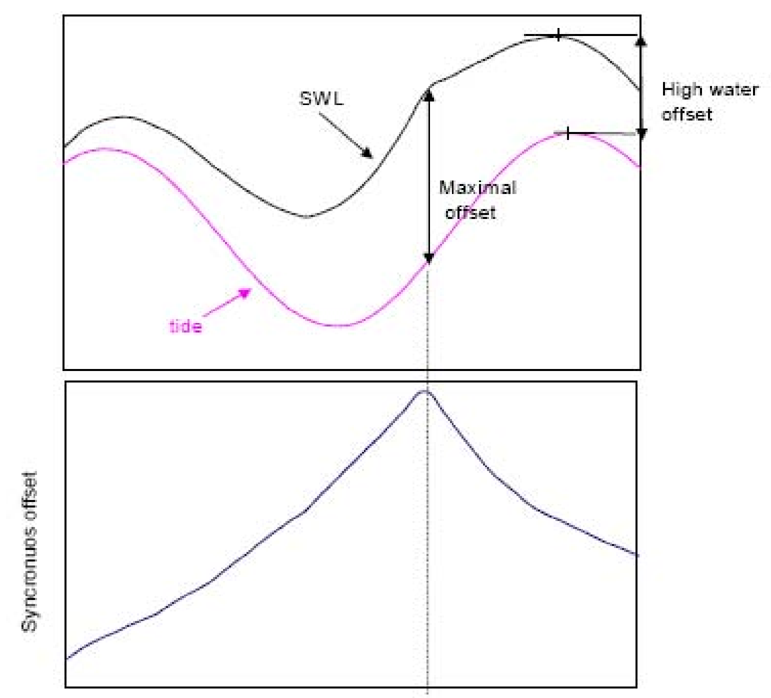
- skew High Water offset

Population:

- Long winter season (October-March)
- 60 hours declustering

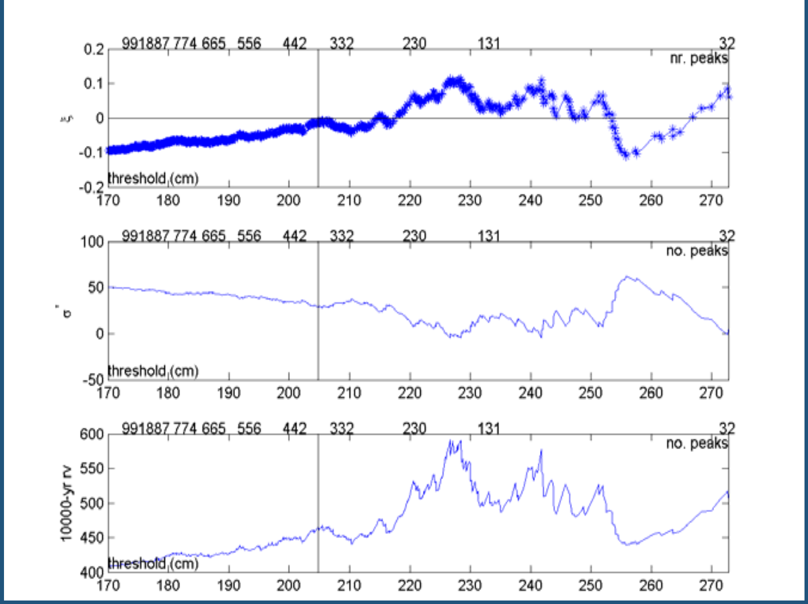
Trend:

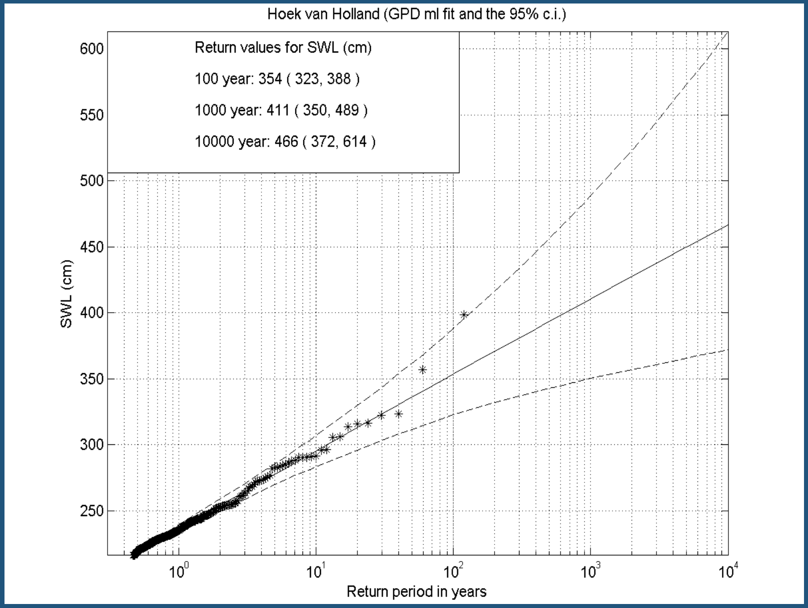
- 0.026 cm/yr, removed, adjusting to the levels of the 2006 long winter season



WL | delft hydraulics

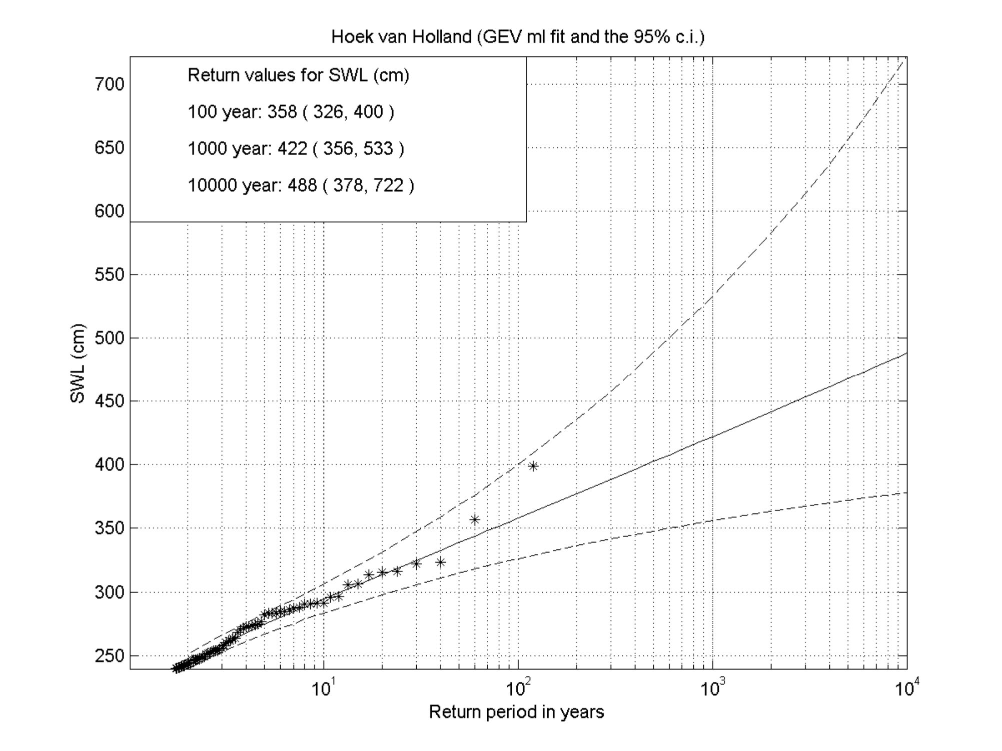
POT/GPD analysis of the SWL data





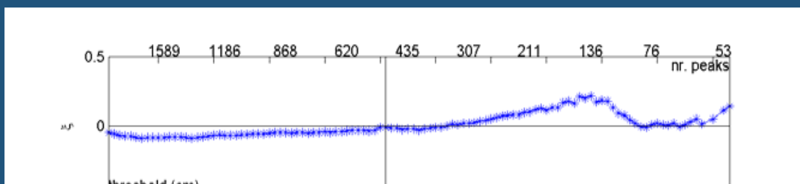
Sample size	u	$\hat{\xi}$	$\hat{\sigma}$
393	205	-0.01 (-0.13, 0.09)	26 (23, 30)

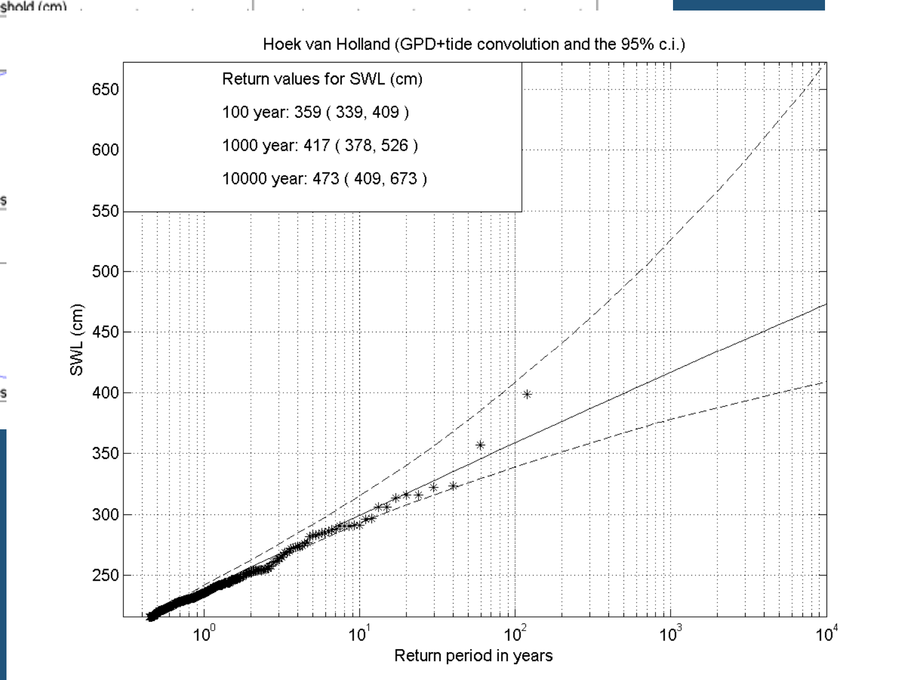
AM/GEV analysis of the SWL data

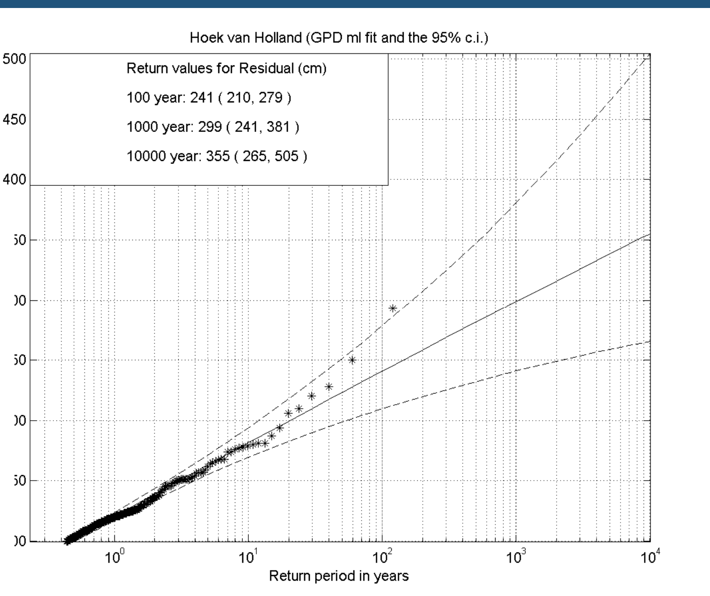


Sample size	$\hat{\xi}$	$\hat{\sigma}$	$\hat{\mu}$
119	0.01 (-0.14, 0.16)	26 (22, 30)	235 (230, 241)

Convolution of astronomical tides and peak surge heights

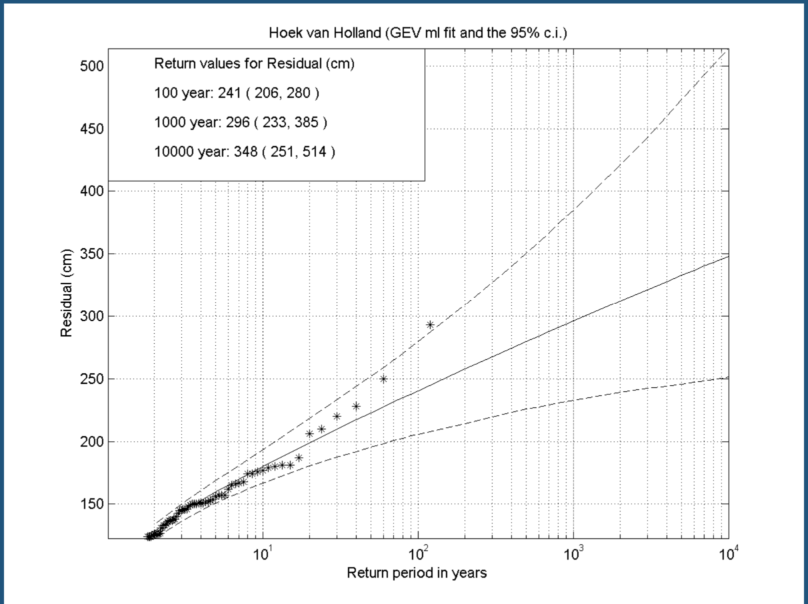


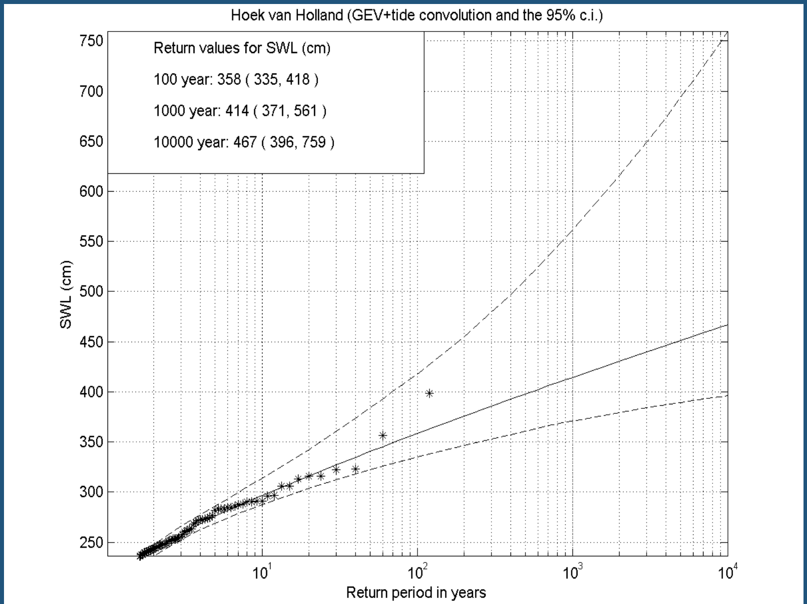




Sample size	u	$\hat{\xi}$	$\hat{\sigma}$
506	81	-0.01 (-0.11, 0.08)	27 (24, 31)

Convolution of astronomical tide and AM surge heights

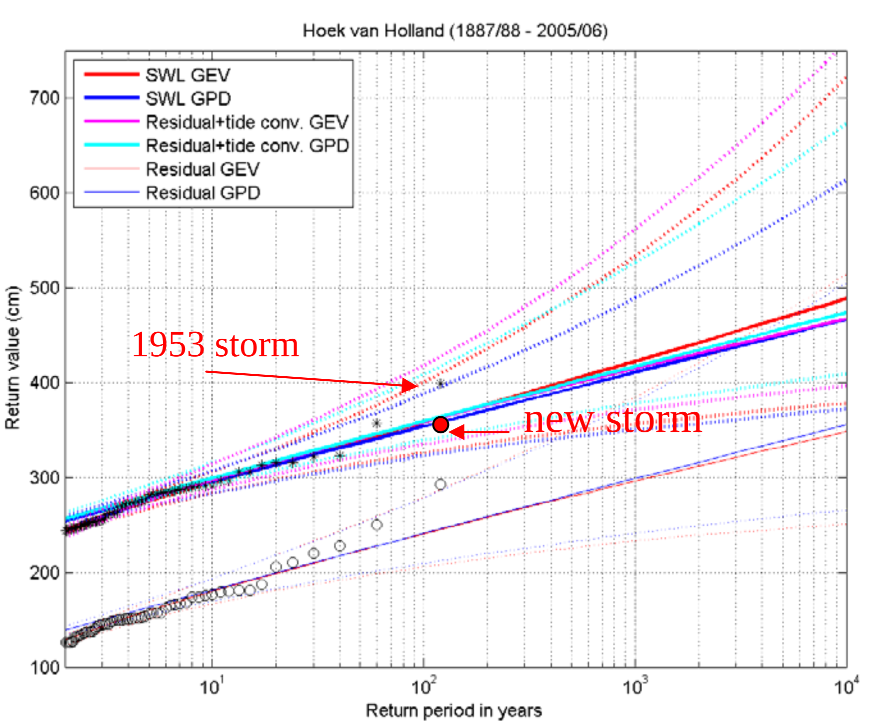




Sample size	$\hat{\xi}$	$\hat{\sigma}$	$\hat{\mu}$
119	-0.03 (-0.17, 0.09)	28 (24, 33)	118 (113, 123)

WL | delft hydraulics

Concluding remarks



	Return period	SWL (cm)	rel. amp. of c.i. (%)
SWL POT/GPD	1/100 years 1/1000 years 1/10000 years	354 (323, 388) 411 (350, 489) 467 (372, 614)	19 34 52
Residual POT/GPD	1/100 years 1/1000 years 1/10000 years	241 (210, 279) 299 (241, 381) 355 (265, 505)	29 47 67
Convolution Residual POT/GPD	1/100 years 1/1000 years 1/10000 years	359 (339, 409) 417 (378, 526) 473 (409, 673)	19 35 56
SWL AM/GEV	1/100 years 1/1000 years 1/10000 years	358 (326, 400) 422 (356, 533) 488 (378, 722)	21 42 70
Residual AM/GEV	1/100 years 1/1000 years 1/10000 years	241 (206, 280) 296 (233, 385) 348 (251, 514)	31 51 75
Convolution Residual AM/GEV	1/100 years 1/1000 years 1/10000 years	358 (335, 418) 414 (371, 561) 467 (396, 759)	23 46 78

Return period	Convolution Residual POT/GPD	SWL AM/GEV	Convolution Residual AM/GEV
1/100 year	1.50	1.25	1.37
1/1000 years	1.54	2.83	0.95
1/10000 years	1.48	4.63	0.07