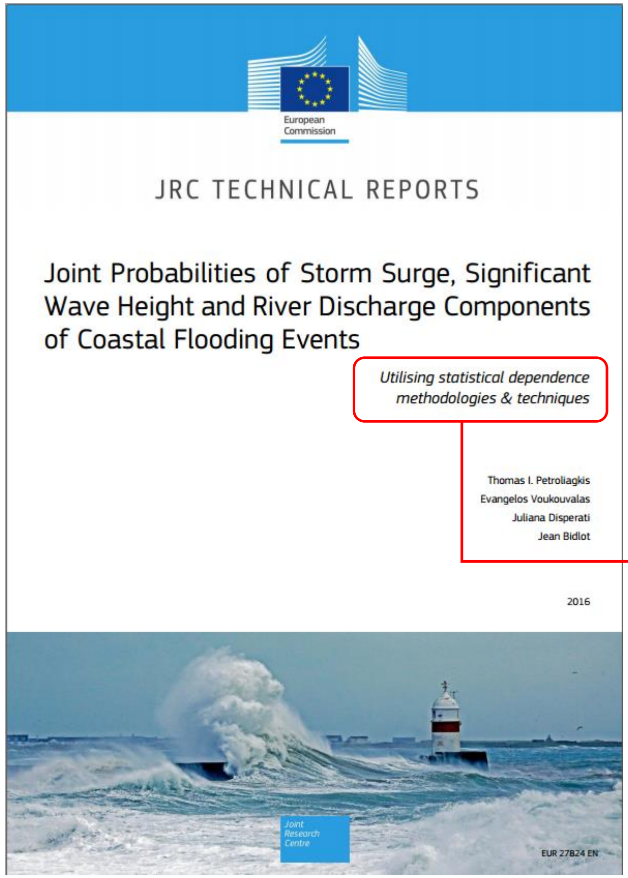
European Commission

Going After High-Impact Compound Events


European Commission

JRC TECHNICAL REPORTS

Joint Probabilities of Storm Surge, Significant Wave Height and River Discharge Components of Coastal Flooding Events

Utilising statistical dependence methodologies & techniques

Thomas I. Petroliagkis
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Juliana Disperati
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2016

Joint Research Centre

EUR 27824 EN

Joint Probabilities of Storm Surges Waves and River Discharges

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Juliana Disperati (JRC)

Jean Bidlot (ECMWF)

Paul Dando & Carsten Maass (Support)

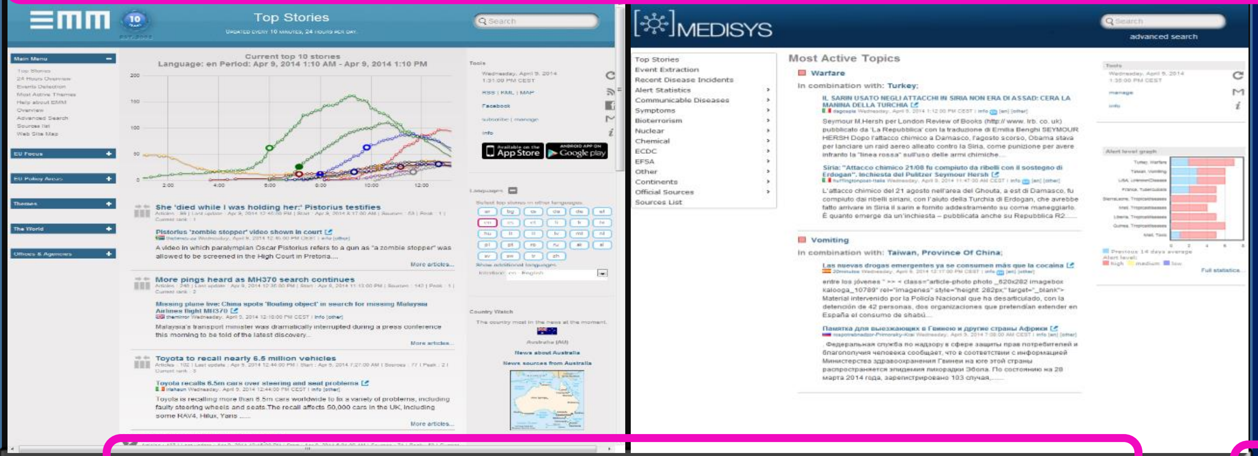
Utilising statistical dependence methodologies & techniques

UEF2016, 6-9 June 2016, ECMWF, Reading, U.K.

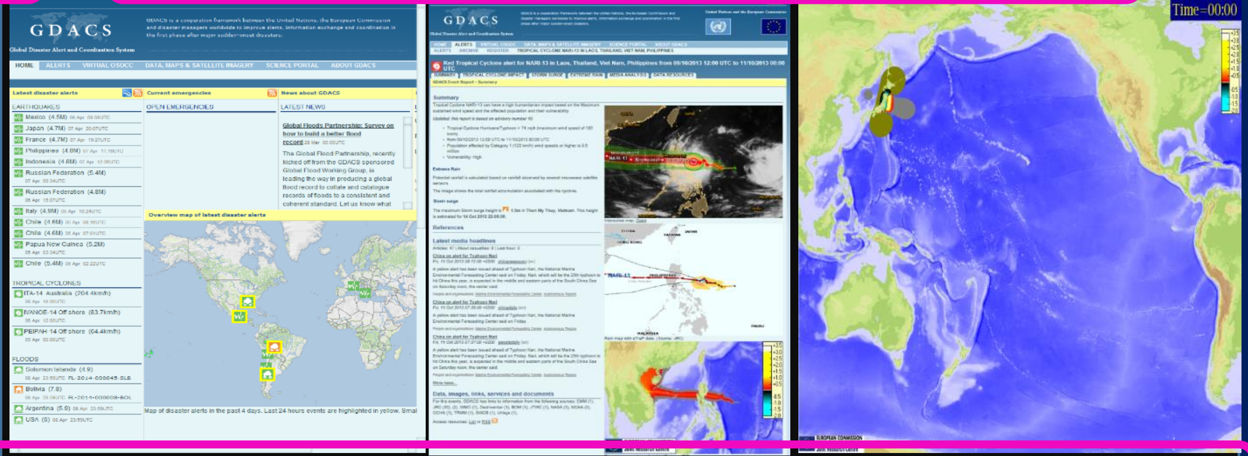
Joint Research Center

Global Security & Crisis Management Unit
Institute for Protection & Security of Citizen (Joint Research Center)

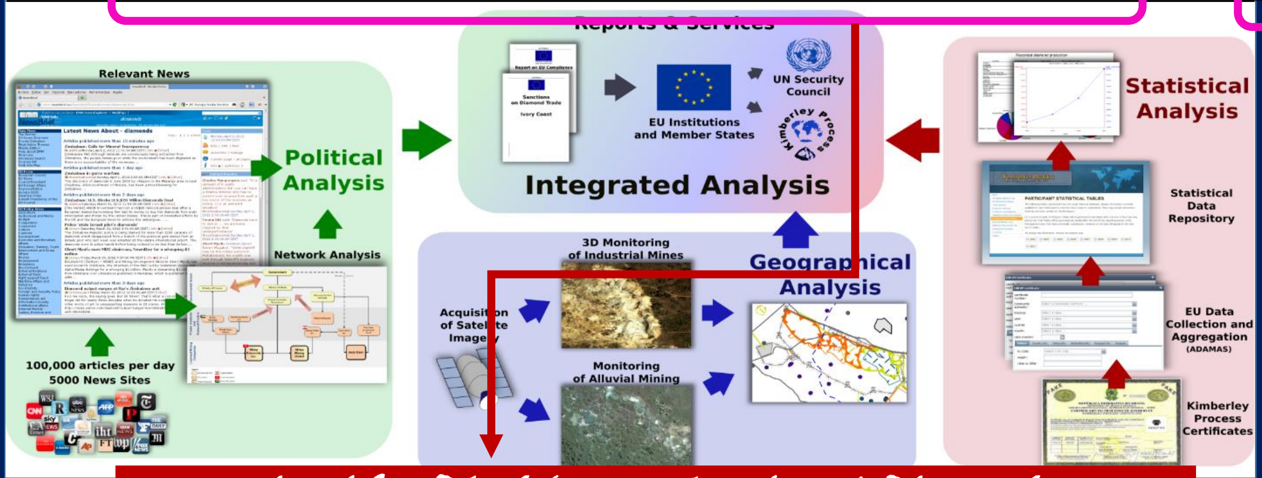
Open Source Monitoring for Media Analysis and Security



Natural Disasters Monitoring and Analysis

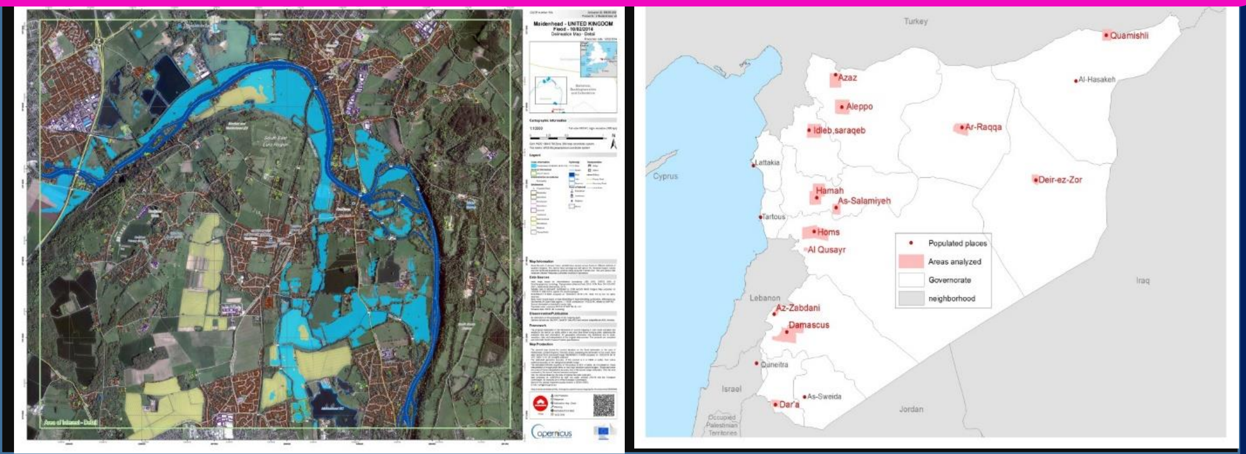


Conflict Prevention through the Kimberly Process

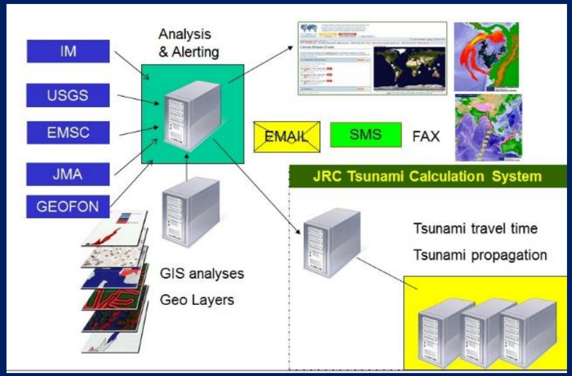


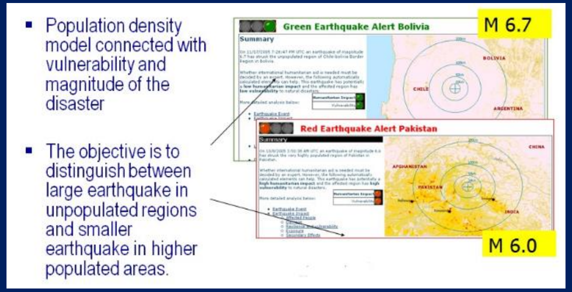
Going After Blood (War - Torn Areas) Diamonds...

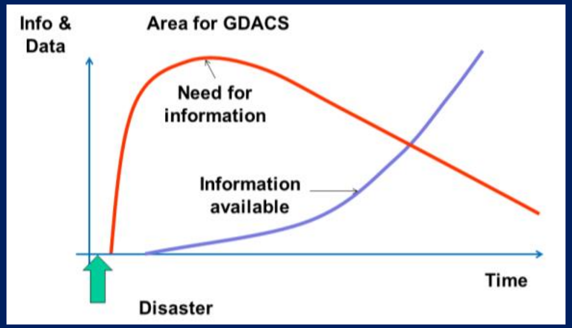
European Emergency Mapping & International Reconstruction



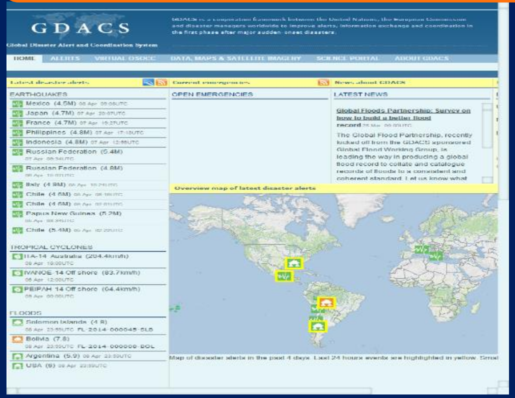
Natural Disasters Monitoring and Analysis
Global Disaster Alert & Coordination System

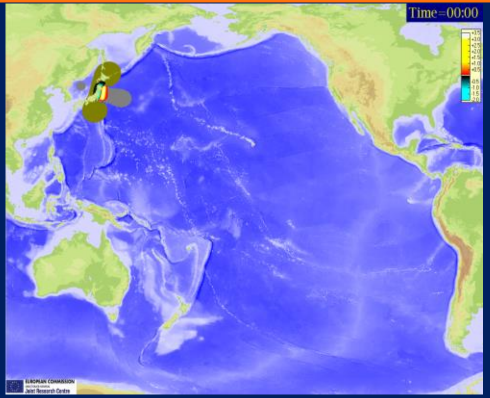




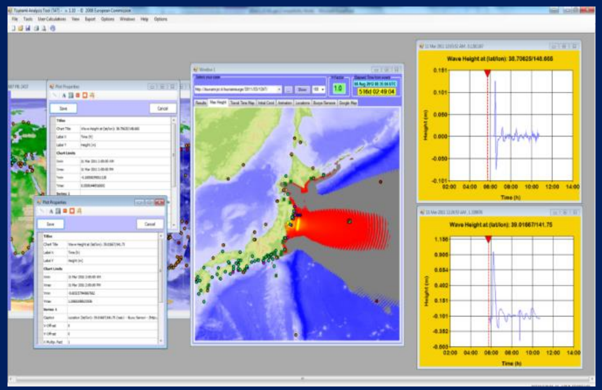


www.gdacs.org JRC – UN – OCHA – UNOSAT

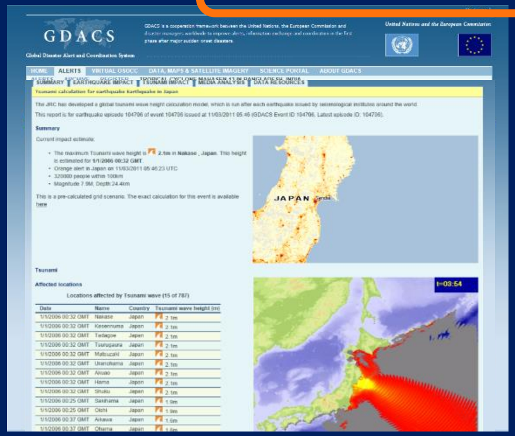


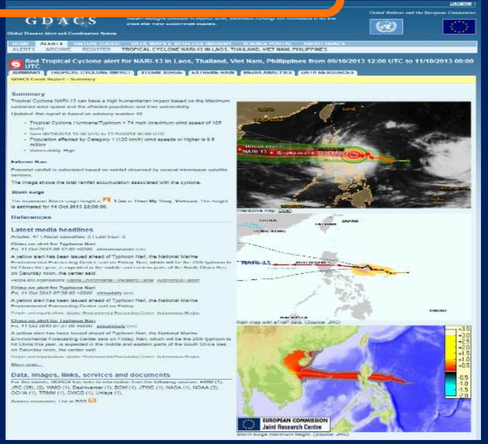


Tsunami Analysis Tool (TAT)

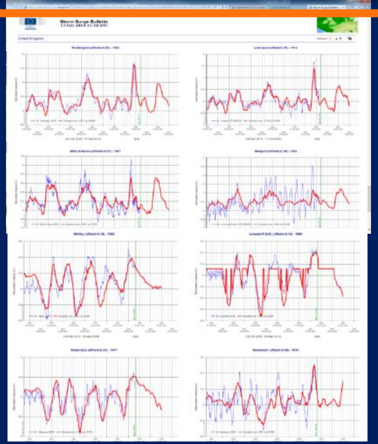


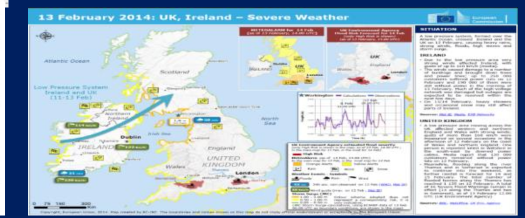
Tropical Cyclone Impacts



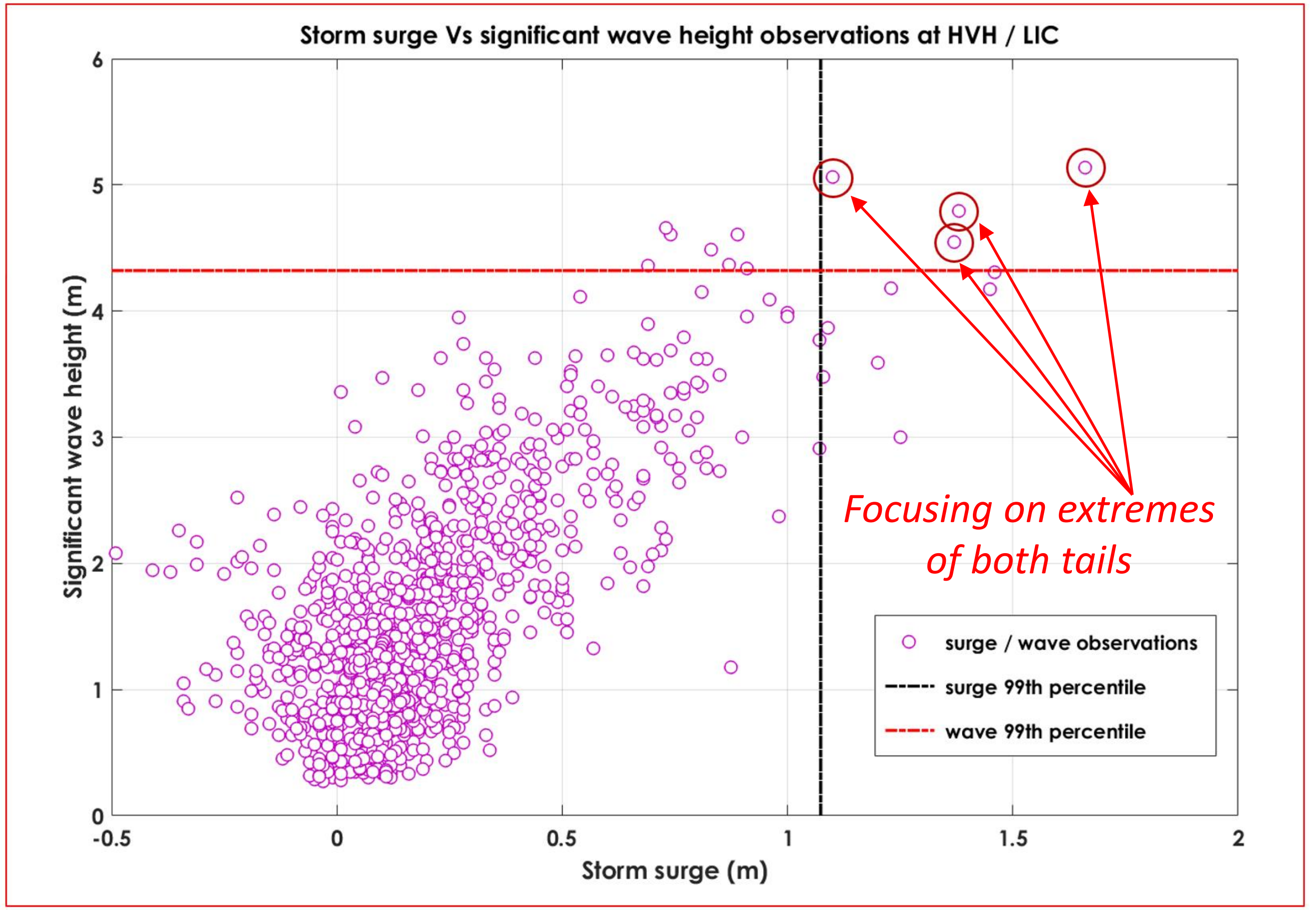


Storm Surge Monitoring & Daily Bulleting





Focusing on Wind – Precipitation & Storm Surge Impact(s)



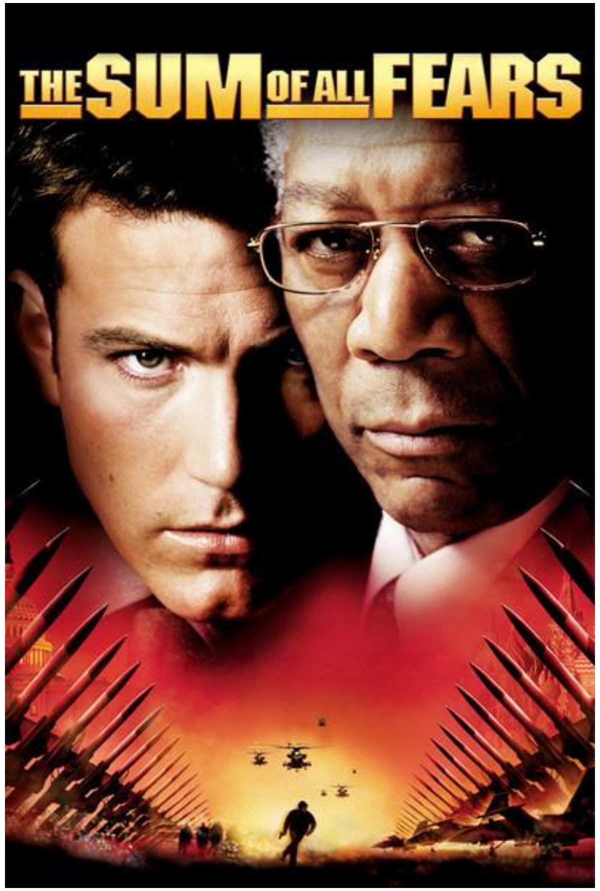
CoastAlRisk

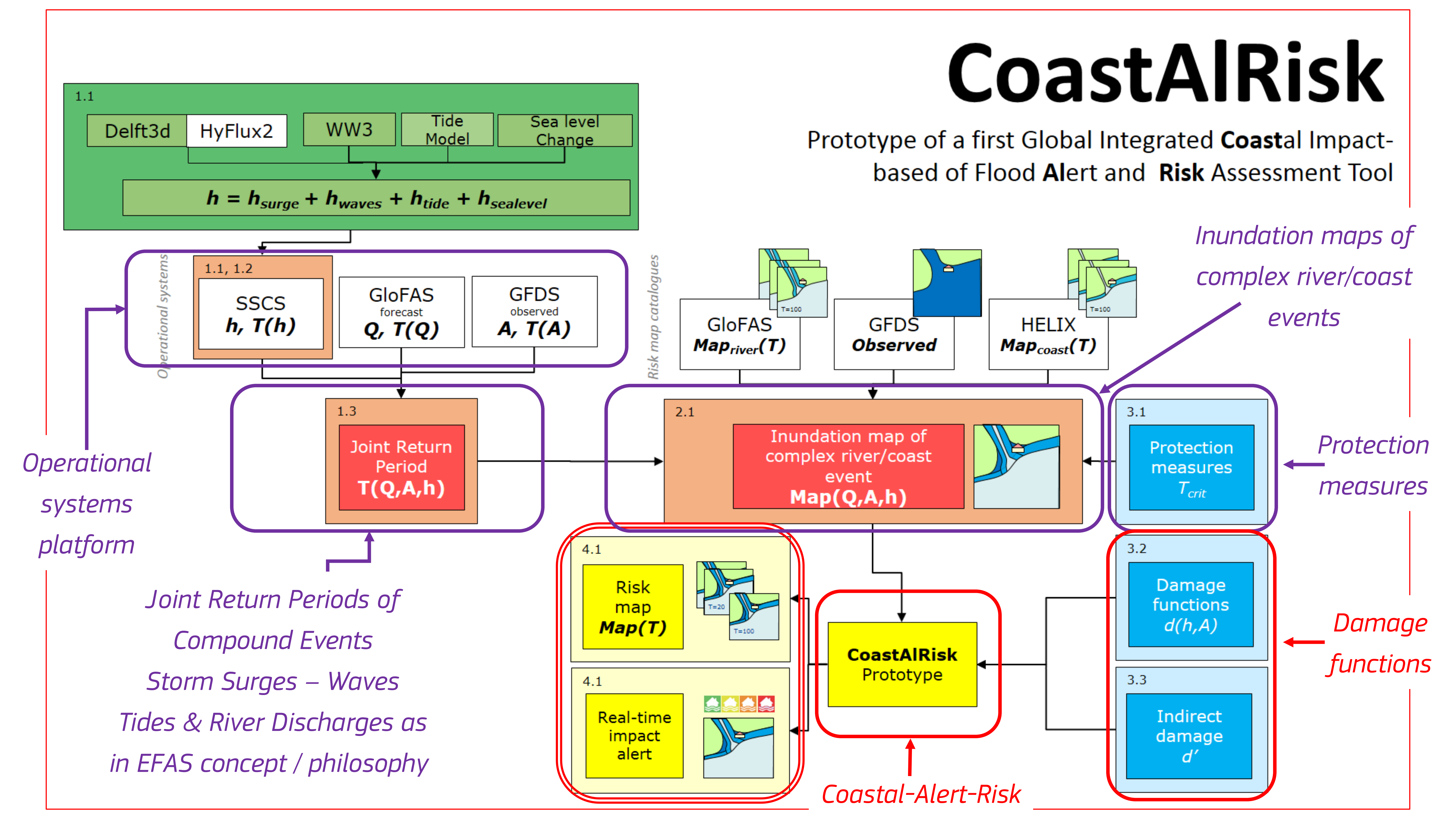
Prototype of a first Global Integrated **Coast**al Impact-based of Flood **Al**ert and **Risk** Assessment Tool

IPCC, 2012: Compound Events

special category of weather / climate extremes, resulting from the combination of two or more events, i.e. extremes either from a statistical perspective (tails of distribution) or associated with a specific (critical) threshold(s) …

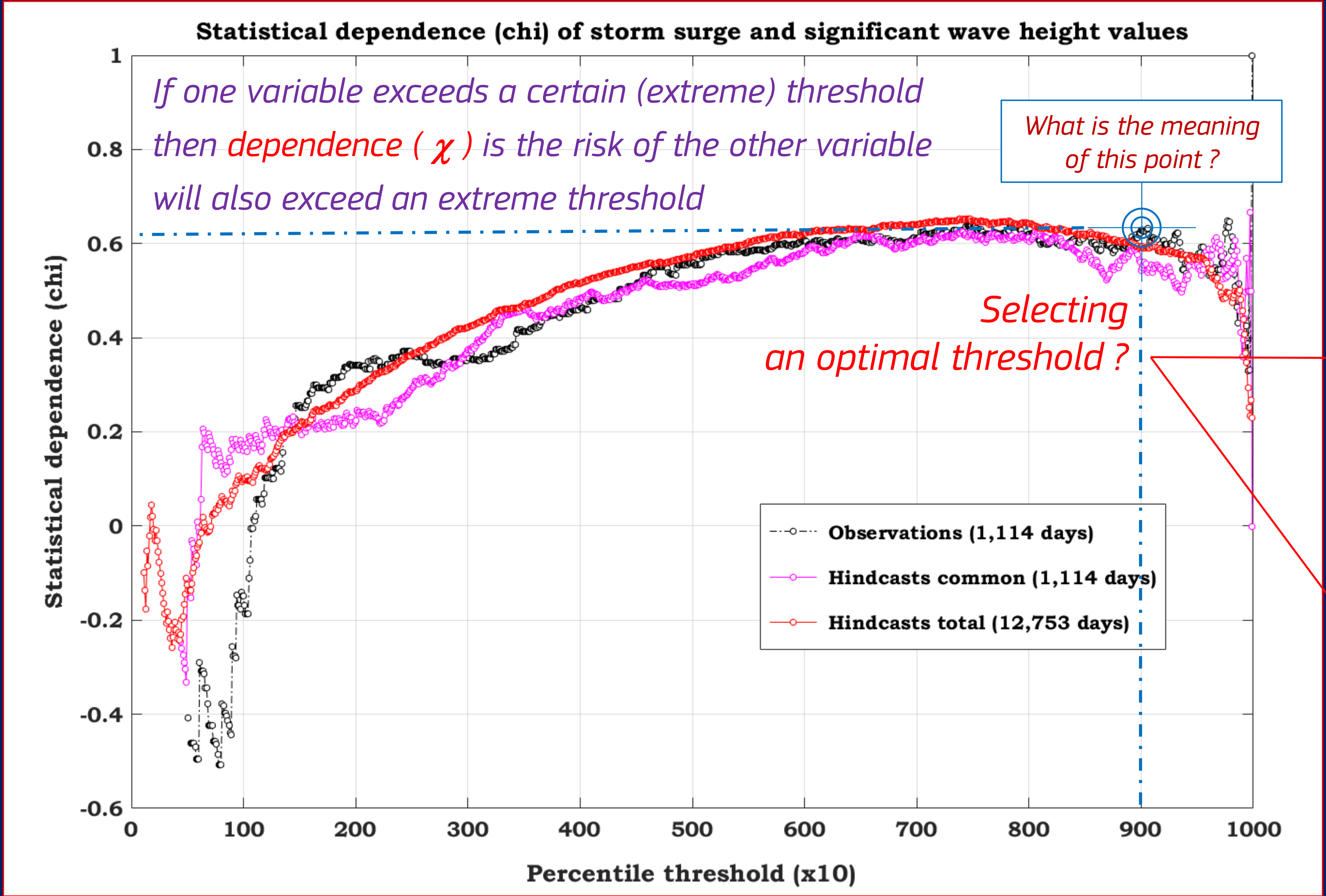
The Exploratory Research Project Coastal-Alert-Risk of the Joint Research Center has been an initial effort of developing the first global integrated coastal flood risk management system with emphasis on such compound events, by linking satellite monitoring, coupled wave, tide and surge forecasting, inundation modelling and impact analysis





CoastAlRisk
Prototype of a first Global Integrated Coastal Impact-based of Flood Alert and Risk Assessment Tool
1.1
Delft3d
HyFlux2
WW3
Tide Model
Sea level Change
$h = h_{surge} + h_{waves} + h_{tide} + h_{sealevel}$
Operational systems
1.1, 1.2
SSCS
h, T(h)
GloFAS
forecast
Q, T(Q)
GFDS
observed
A, T(A)
Risk map catalogues
GloFAS
$Map_{river}(T)$
T=100
GFDS
Observed
HELIX
$Map_{coast}(T)$
T=100
Inundation maps of complex river/coast events
1.3
Joint Return Period
T(Q,A,h)
2.1
Inundation map of complex river/coast event
Map(Q,A,h)
3.1
Protection measures
T_{crit}
Protection measures
Operational systems platform
Joint Return Periods of Compound Events
Storm Surges – Waves
Tides & River Discharges as
in EFAS concept / philosophy
4.1
Risk map
Map(T)
T=20
T=100
4.1
Real-time impact alert
CoastAlRisk
Prototype
Coastal-Alert-Risk
3.2
Damage functions
d(h,A)
3.3
Indirect damage
d'
Damage functions

Estimating joint probabilities by utilising statistical dependencies of component events



WHY ?

Dependence can modulate Joint Return Period …

Firstly
to have enough data points above the threshold to be able to determine dependence

and secondly
the threshold to be high enough to regard the values as extreme (Svensson and Jones 2003)

Example of how statistical dependence (chi) modulates joint return period

$$T_{X,Y} = \sqrt{\frac{T_x \cdot T_y}{\chi^2}}$$

$T_{x,y}$ = Joint Return Period

T_x = Return Period (surge)

T_y = Return Period (wave)

Utilizing matlab routines to fit GEV (General Extreme Value) Distributions to surge & wave values both 100-year return period values of total hindcast datasets for HVH (storm surge) / LIC (significant wave) were estimated …

	Surge / 100 RP	Wave / 100 RP	chi	JRP
Hind total	1.78	6.05	0.5730	174.53

Probability *of the combined event in total hindcasts mode*

surge = 1.78 & wave height = 6.05 meters

to be exceeded in a year

if considered independent events is given by

1/100 x 1/100 = 1 / 10,000 = 0.0001%

However, in case of chi = 0.57

JRP = 174.95 years

Then probability of exceeding

= 1 / Joint Return Period = 1/174.95 = 0.0057

(~57 times higher)

Svensson & Jones, 2003. Dependence between extreme sea surge, river flow & precipitation: A study in south & west Britain. R&D Interim Technical Report FD2308/TR3 to Defra. CEH Wallingford, UK.

Considering **U** and **V** with distributions [0, 1]

and a critical threshold **(u)**

$$P(V > u \mid U > u) = \frac{P(U > u, V > u)}{P(U > u)}$$

$$\chi(u) = 2 - \frac{\ln P(U \le u, V \le u)}{\ln P(U \le u)} \quad \text{for } 0 \le u \le 1$$

$$P(U \le u, V \le u) = \frac{\textit{Number of } (X,Y) \textit{ such that } X \le x^* \textit{ and } Y \le y^*}{\textit{Total number of } (X,Y)}$$

$$\ln P(U \le u) = \frac{1}{2}\ln\left[\frac{\textit{Number of } X \le x}{\textit{Total number of } X} \cdot \frac{\textit{Number of } Y \le y^*}{\textit{Total number of } Y}\right]$$

since we are after the Joint Return Period … T_{xy} so, we need the value of dependence

$$T_{X,Y} = \sqrt{\frac{T_x \cdot T_y}{\chi^2}}$$

The theoretical return period is the inverse of the probability that a certain event will be exceeded in any one year …

To define the number of extremes two (2) methodologies exist

- Annual (Block) Maxima &

- Peaks-Over-Threshold (POT)

Svensson & Jones, 2003. Dependence between extreme sea surge, river flow & precipitation: A study in south & west Britain. R&D Interim Technical Report FD2308/TR3 to Defra. CEH Wallingford, UK.

From Svensson & Jones (2003)

If **a** is the annual maximum

non-exceedance probability

a = Prob(Annual maximum ≤ x)

then Return Period: **Ta = 1 / (1-a)**

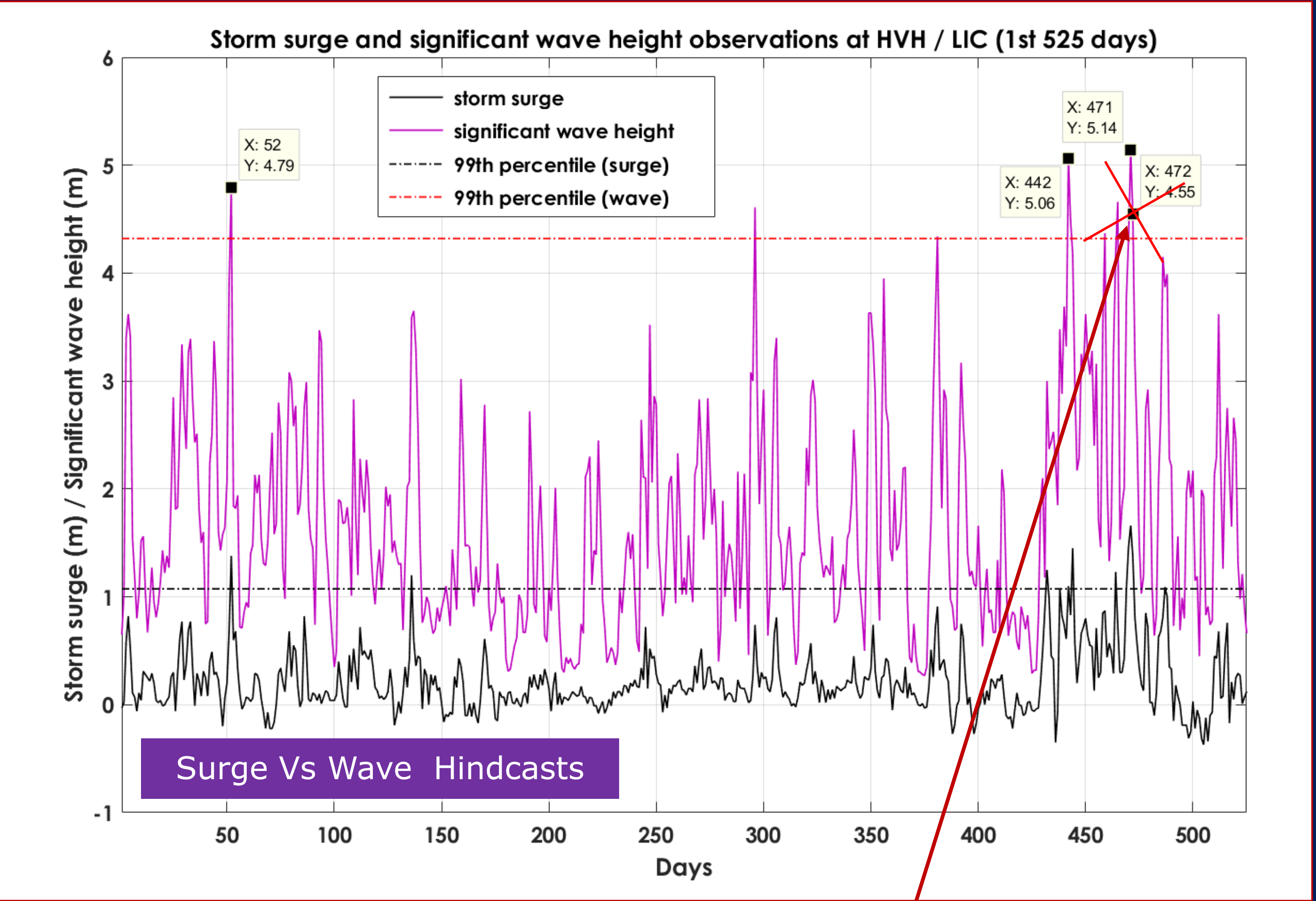
For Peaks-Over-Threshold (POT)

Not referring to an annual maximum

with **p** as non-exceedance probability

of POT series

and the rate of **λ** events per year



a = exp (-λ (1-p)) … For our estimations we adapt

~2.3 events / yearly to exceed that → **a = 0.1 …**

based on the number of the events being allowed to exceed yearly **~2.3 (max ~2.5)**

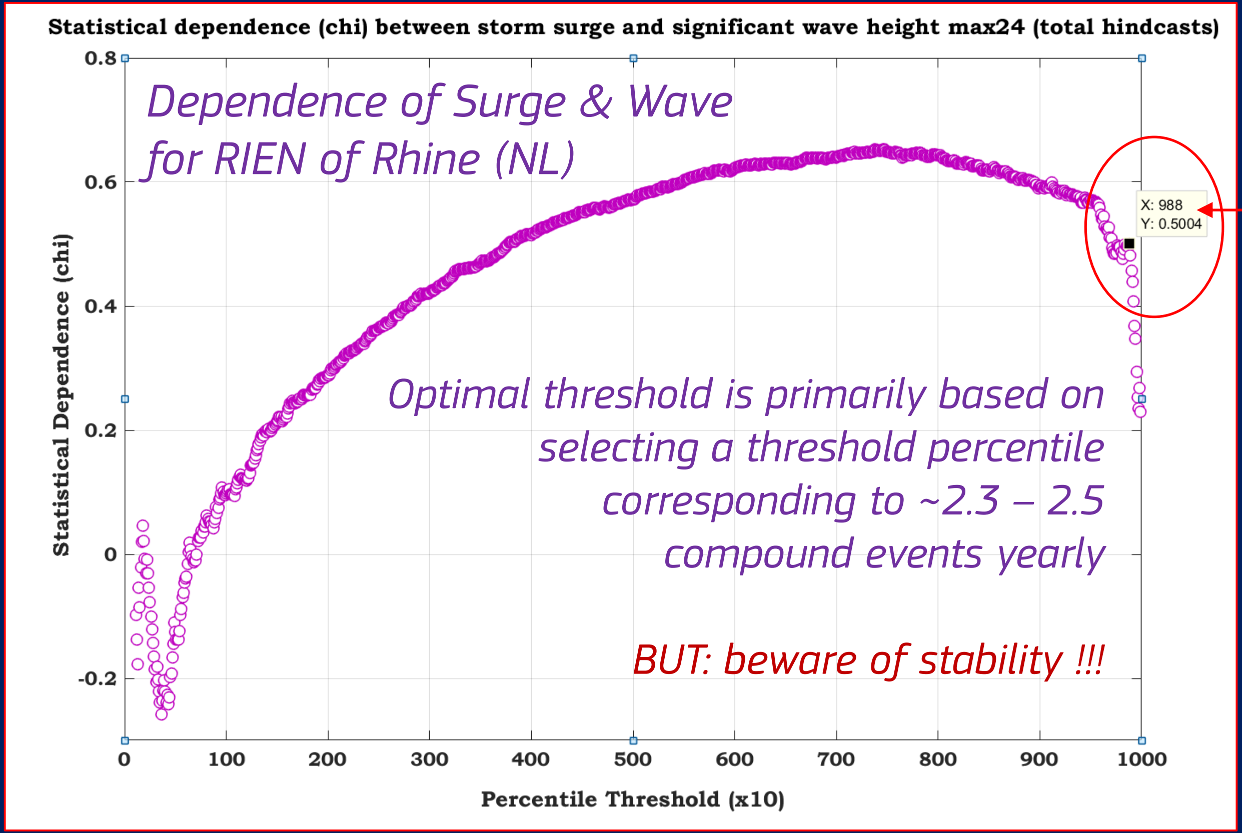
we have the ability to define an **appropriate percentile threshold**

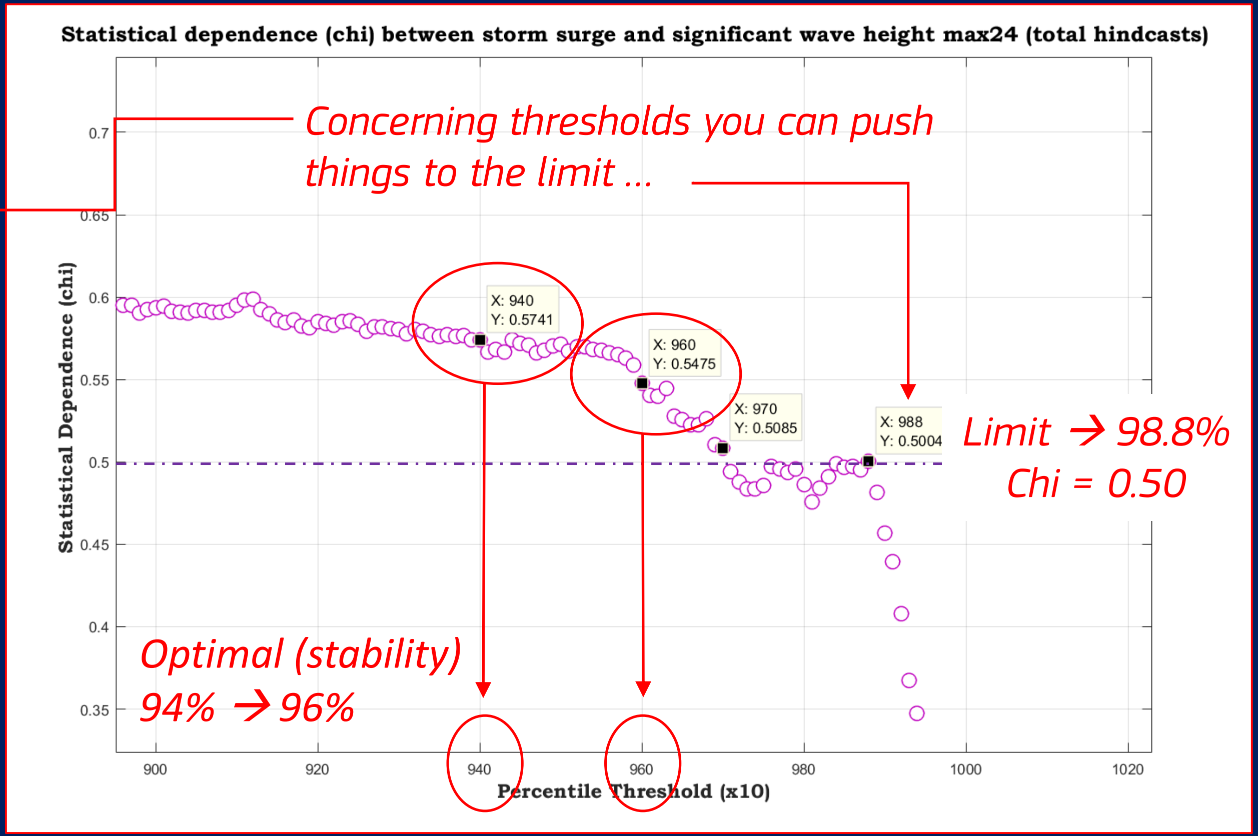
POT example of skipping

consecutive events

falling inside

3-day block …



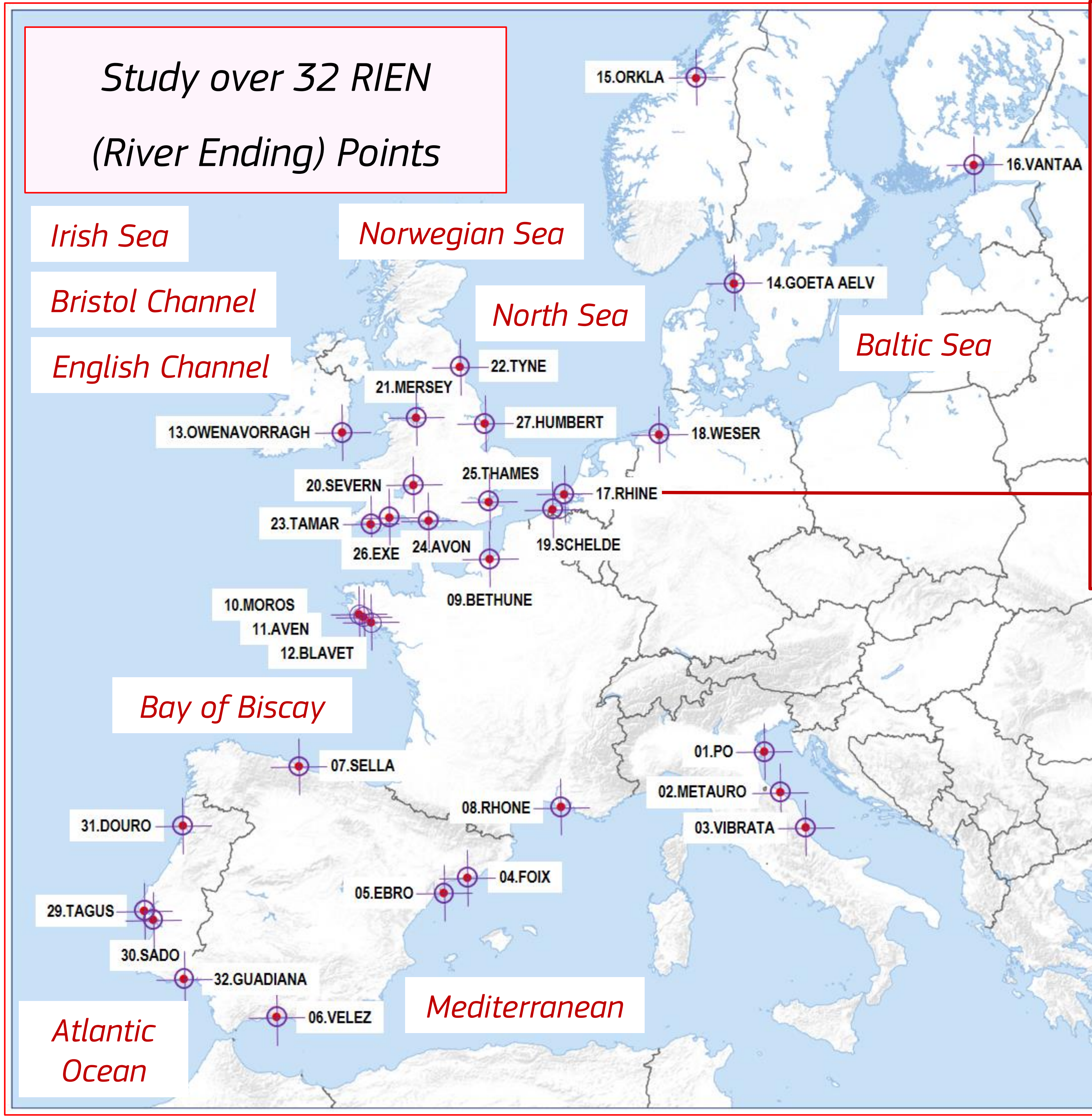


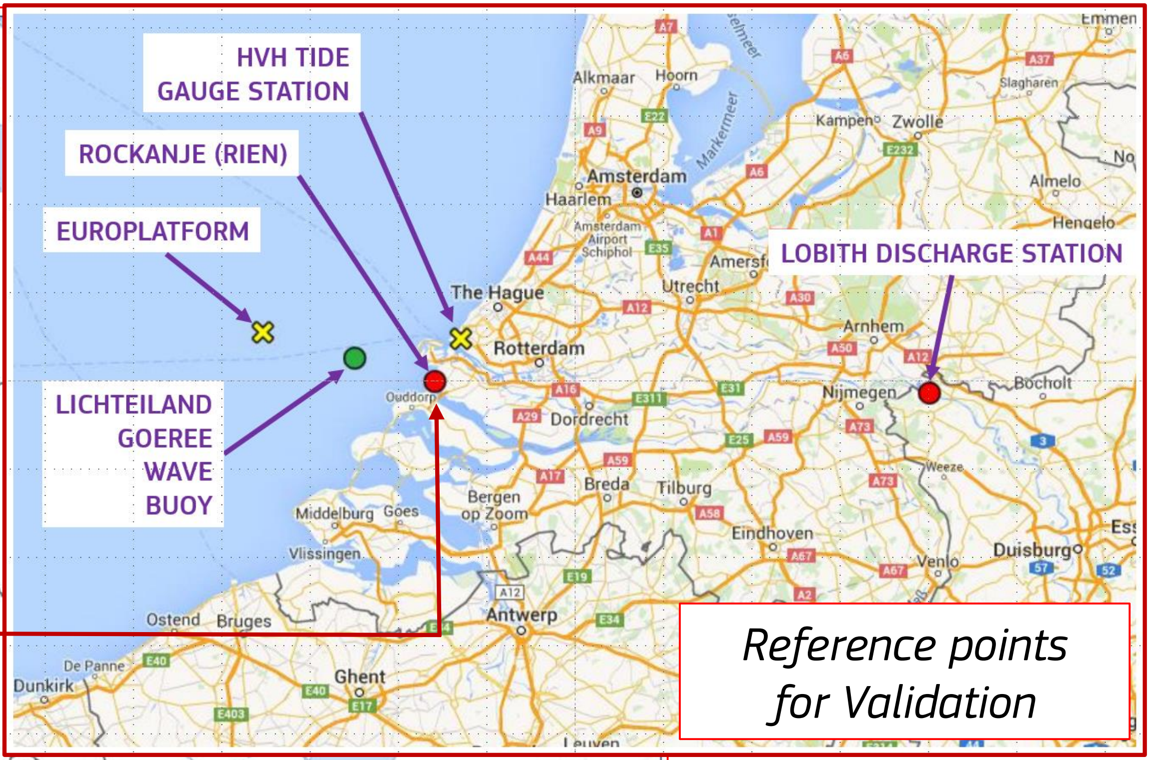
RIEN	River	CHI	Max	Type	Per	CHI (R)	Max (R)	Type (R)
17	Rhine (NL)	0.5475	*	super	0.0	0.5739	*	super

Selecting optimal threshold besides stability
has to be in harmony with ~2.3 – 2.5 events per year
if NOT then: selection of another threshold to meet imposed criteria
most of the times (but not all) a higher value percentile leading to lower values of dependence

for this case selected threshold 95%

Study over 32 RIEN (River Ending) Points





Reference points for Validation

Hindcasts			
Variables	*Start*	*End*	*No. of days*
Waves – HS / Storm Surge	1 Jan 1980	30 Nov 2014	12,753
Waves – HS / River Discharge	1 Jan 1990	9 Oct 2013	8,683
Storm Surge / River Discharge	1 Jan 1990	9 Oct 2013	8,683
Observations			
Variables	*Start*	*End*	*No. of days*
LIC Waves – HS / HVH Storm Surge	22 Sep 2010	30 Dec 2014	1,561
LIC Waves / LOB River Discharge	22 Sep 2010	30 Dec 2014	1,561
HVH Storm Surge / LOB River Discharge	4 Apr 2010	30 Dec 2014	1,732
Hindcasts / Observations			
Common Interval for Validation	22 Sep 2010	9 Oct 2013	1,114

Study over 32 RIEN (River Ending) Points

Utilising Hindcasts of Storm Surge, Significant Wave Height & River Discharges

→ Storm surge hindcasts were performed by utilising the hydrodynamic model **Delft3D-Flow** (resol. 0.2 x 0.2 deg) forced by wind and pressure terms from ECMWF ERA-Interim reanalysis

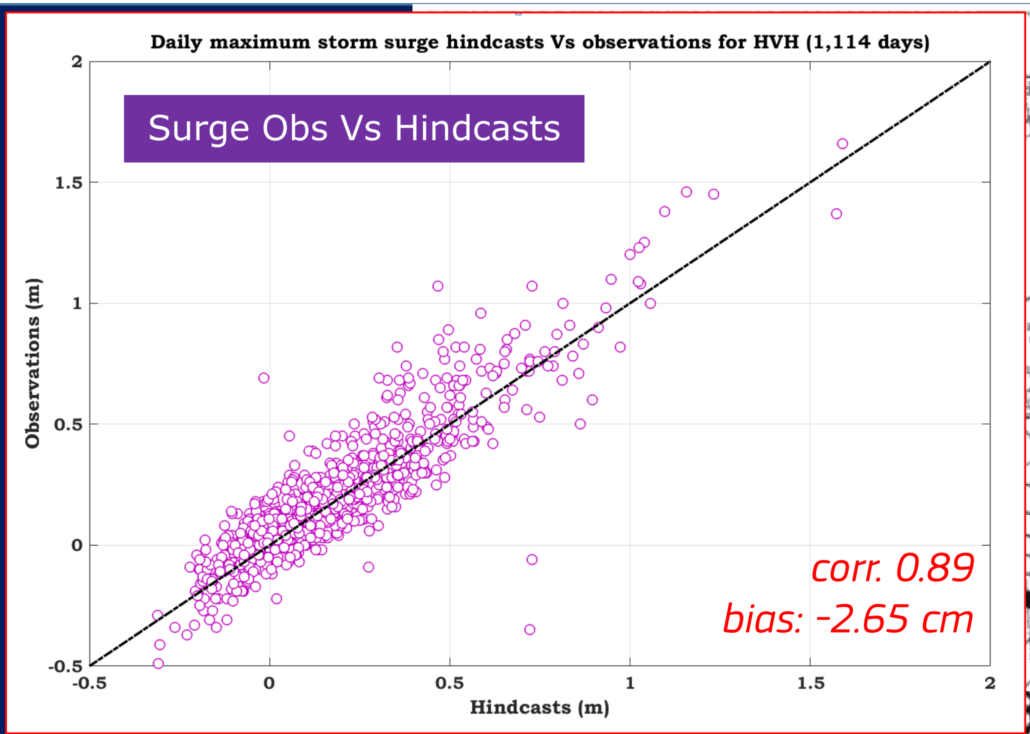
→ Wave hindcasts were generated by latest version of ECMWF **ECWAM** wave (stand-alone) model (resol. 0.25 x 0.25 deg), forced by neutral wind terms from ERA-Interim

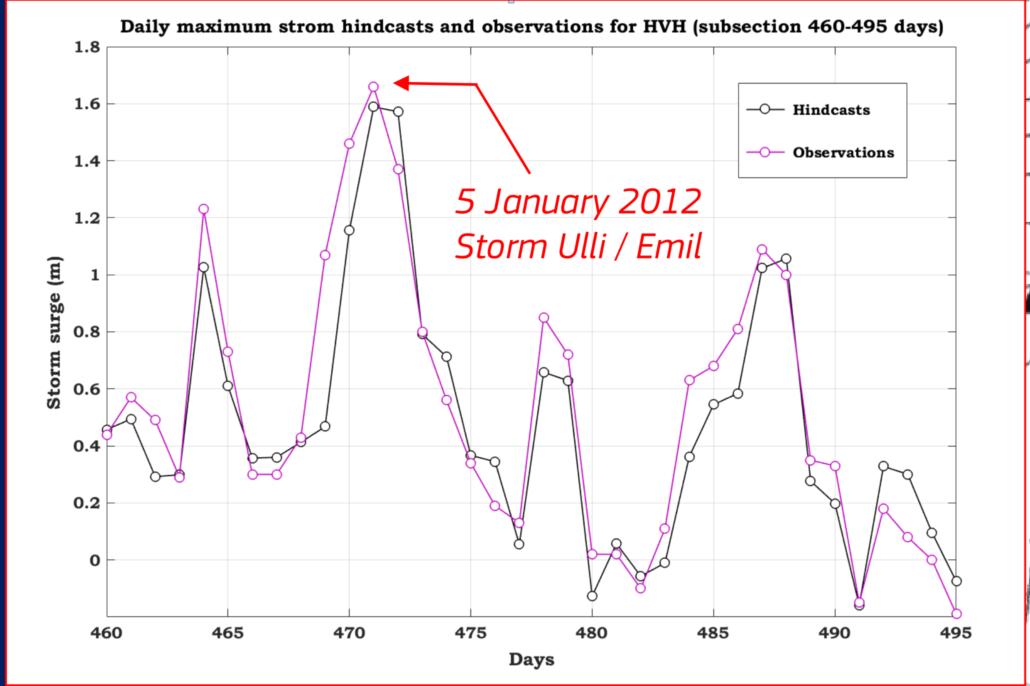
→ For river discharge hindcasts the **LISFLOOD** model developed by the floods group of the Natural Hazards Project of the Joint Research Centre (JRC), was employed (resol. 5 x 5 km)

→ Validation of hindcasts was made over the **RIEN** (River Ending) point of river **Rhine (NL)** where coincident observations were available

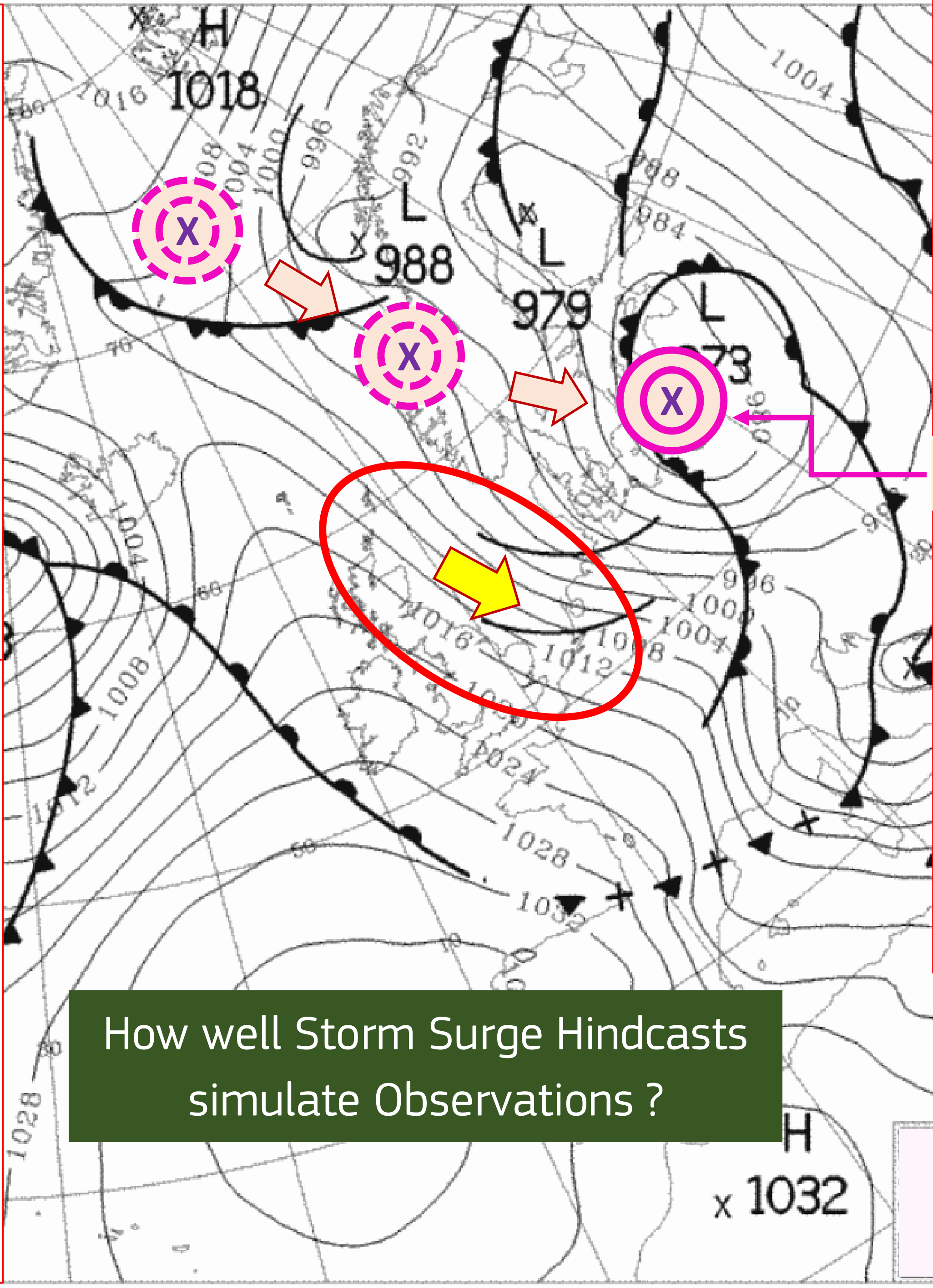
→ Considering the physical driver complexity behind interactions among surge, wave height and discharge variables hindcasts were found to perform quite well, not only simulating observation values over the common interval of interest,

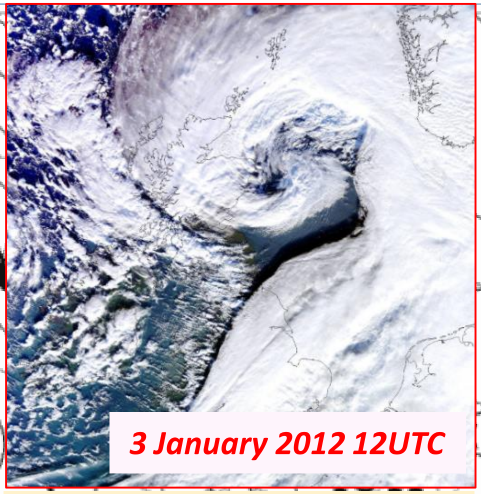
but also in resolving the right type and strength of both correlation and statistical dependence

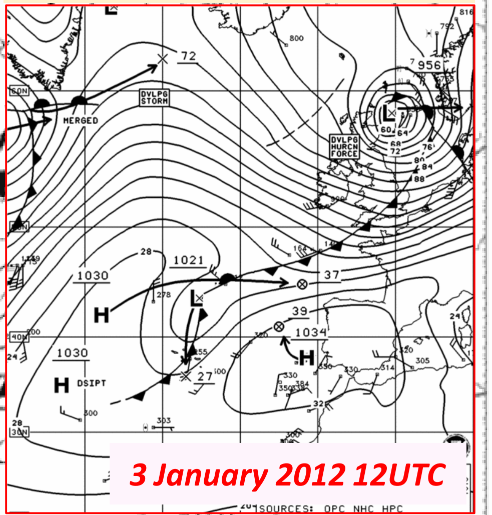


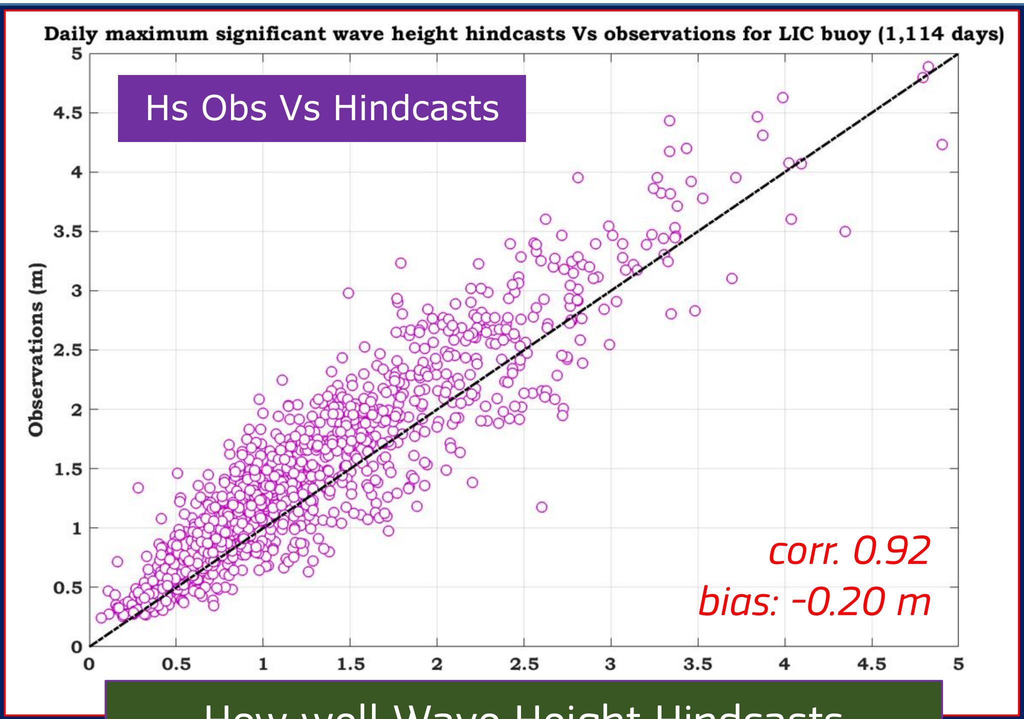


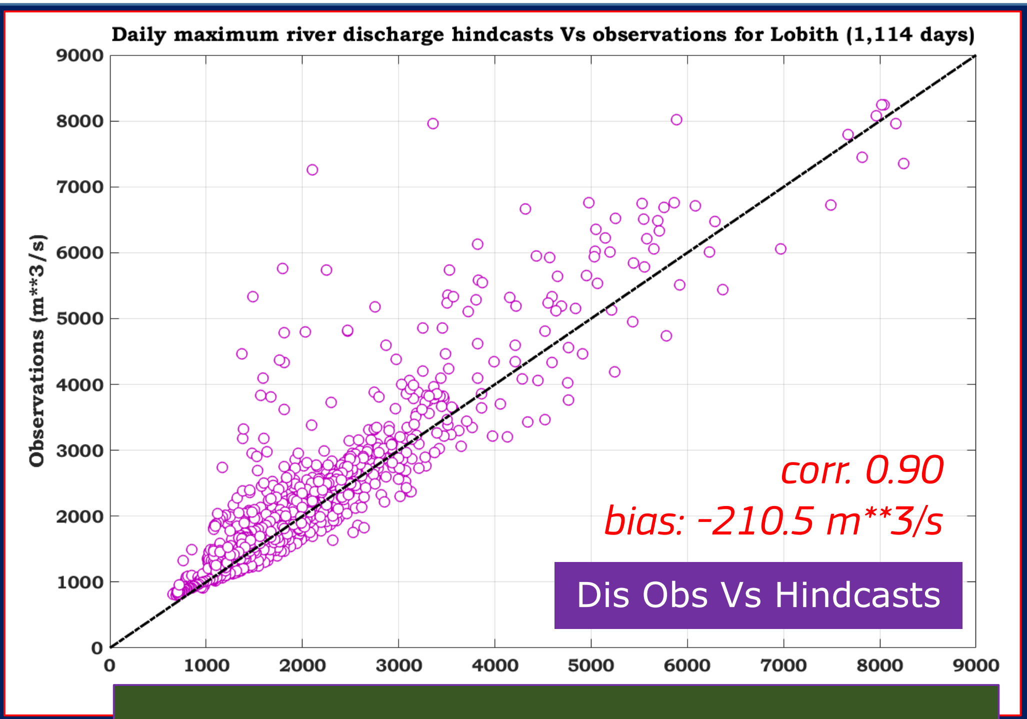
How well Storm Surge Hindcasts simulate Observations ?



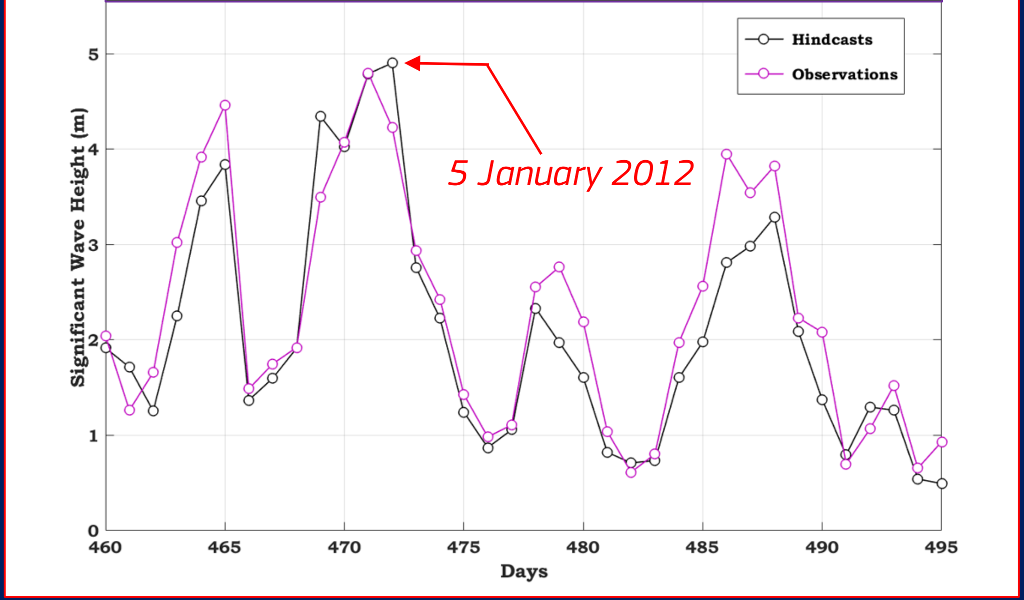




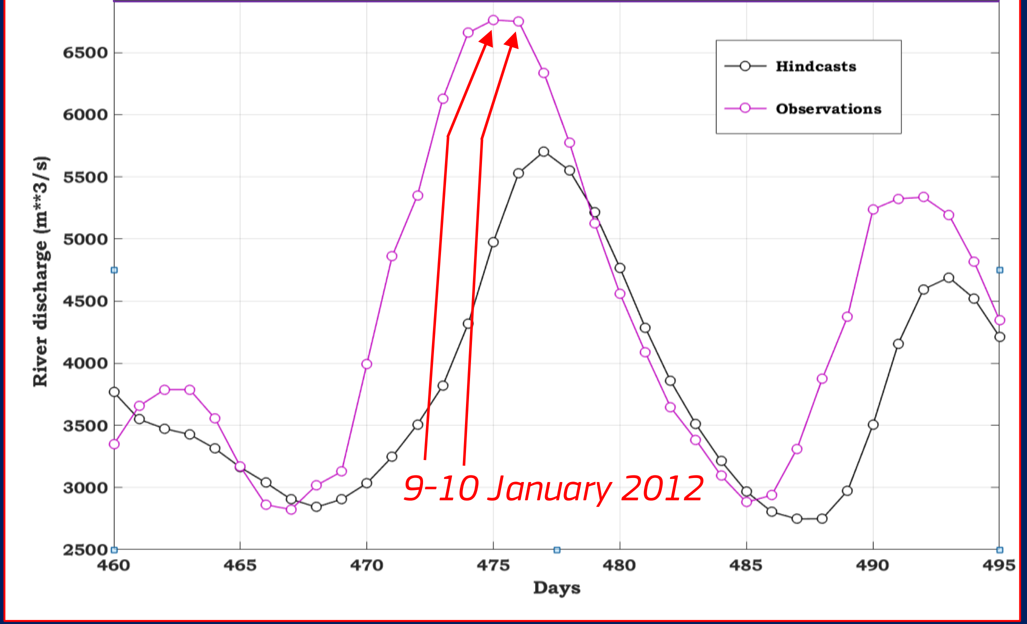


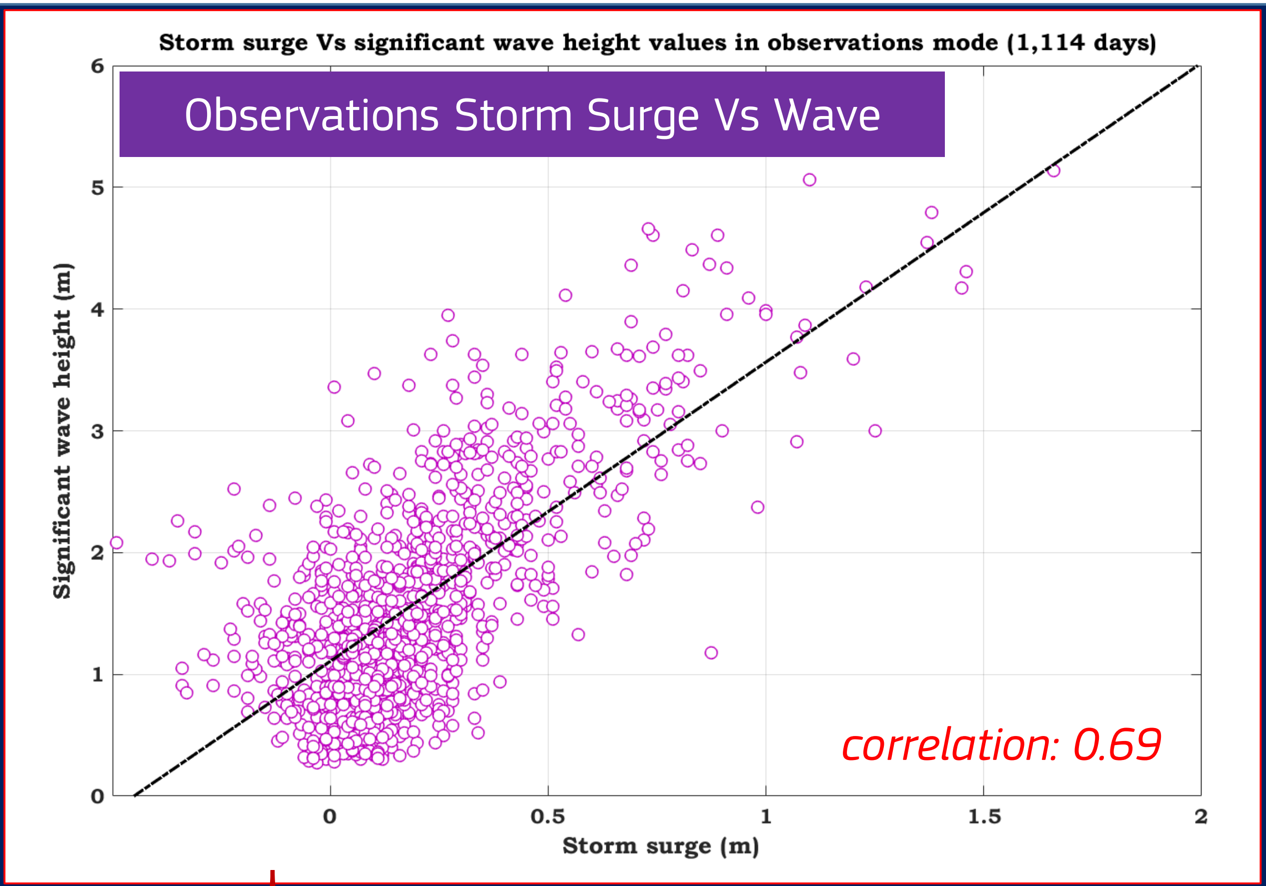


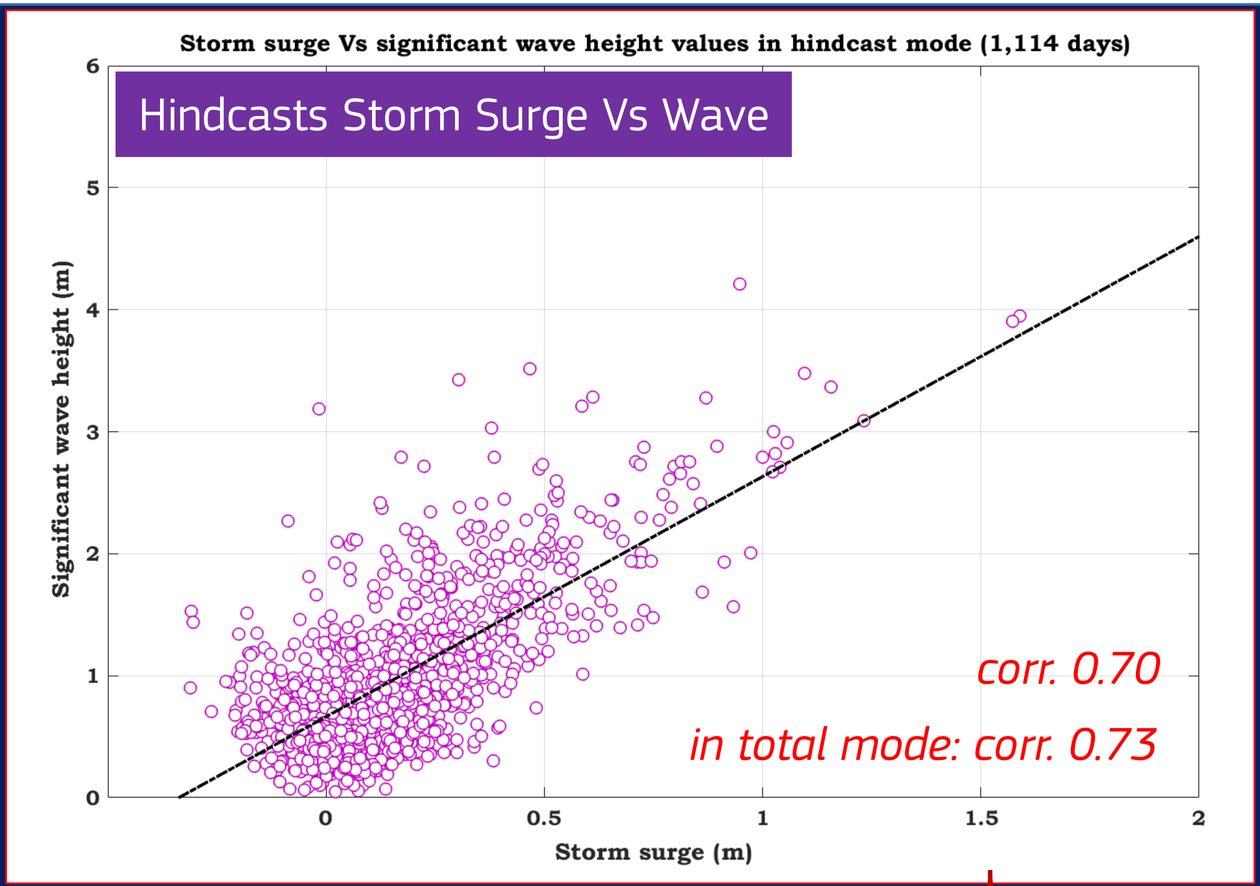
How well Wave Height Hindcasts simulate Observations ?



How well Discharge Observations ?







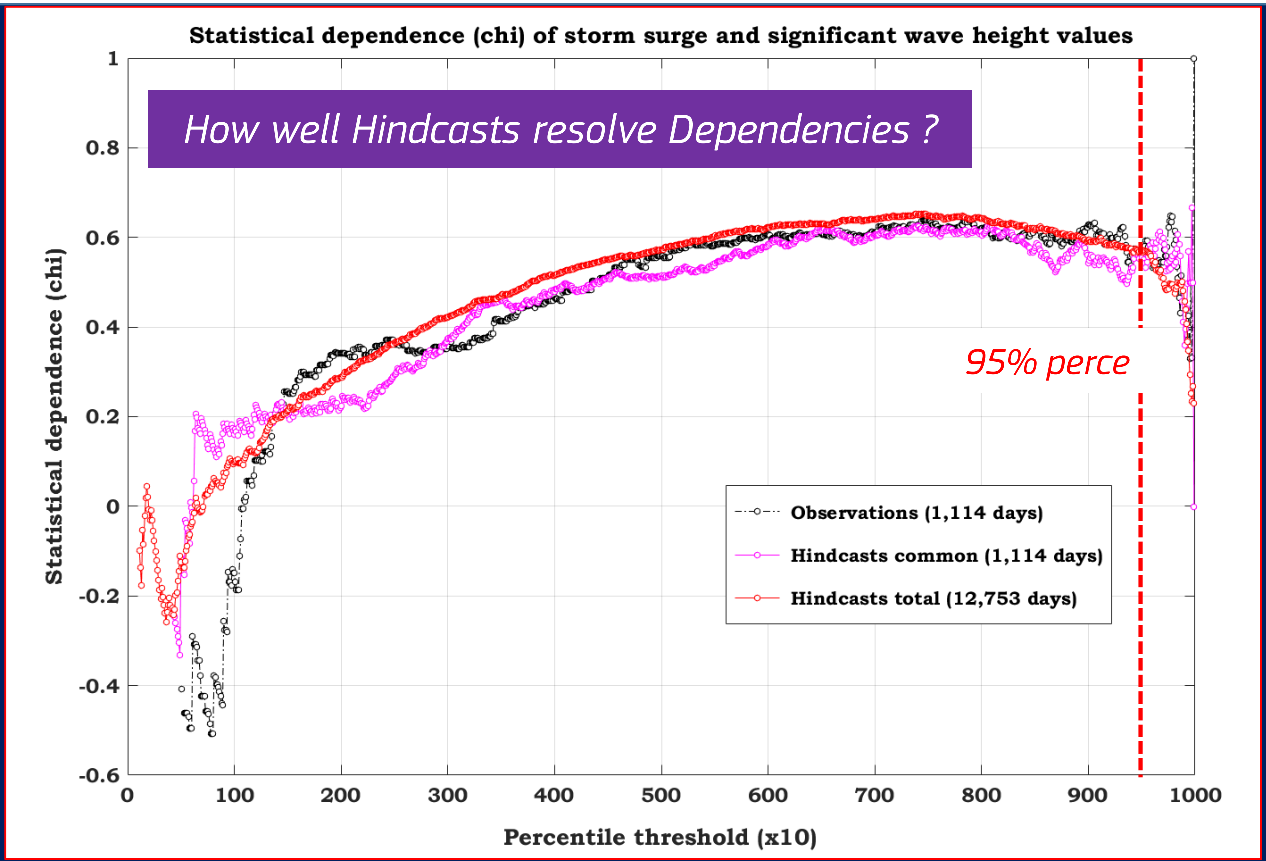
Observations Mode

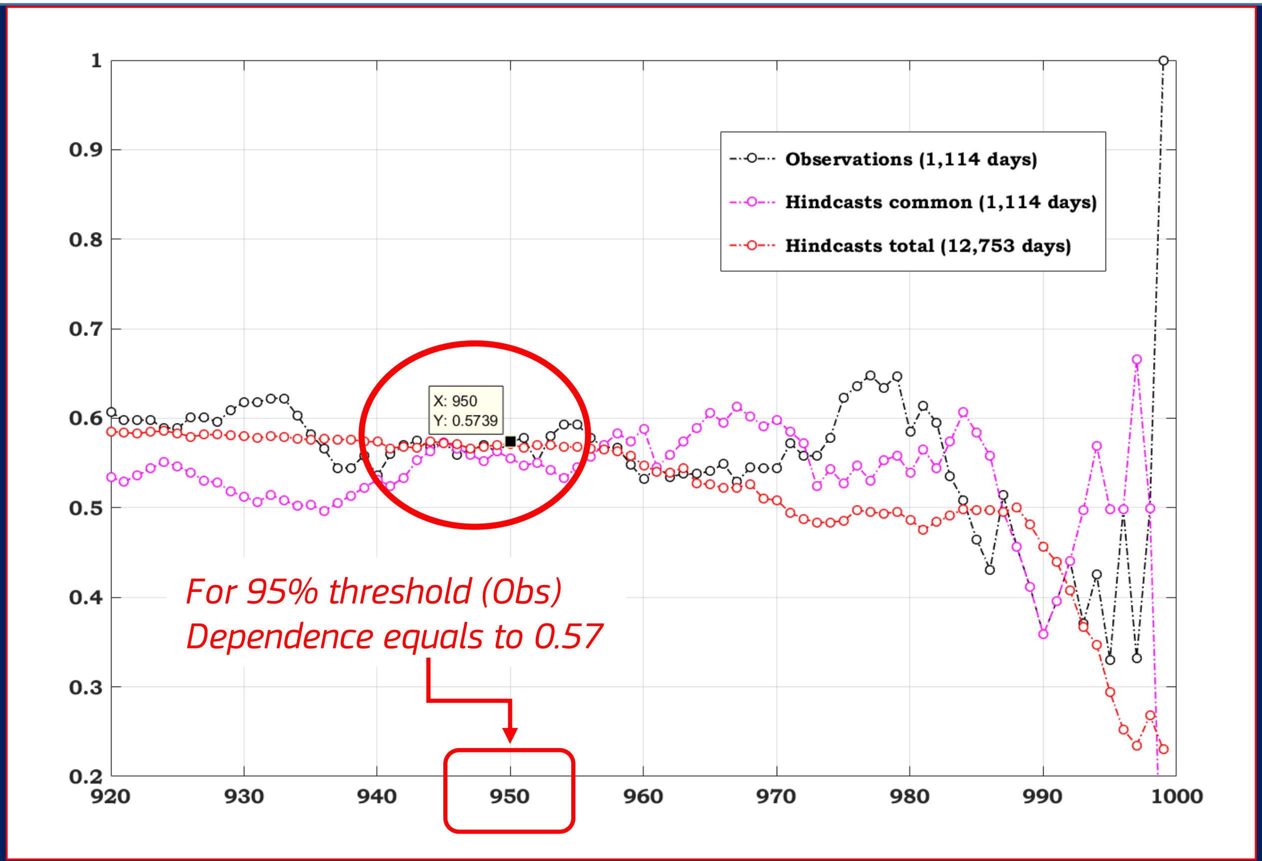
Hindcasts Mode

How well Hindcasts resolve Correlations ?

	obs com	max (lag)	hind com	max (lag)	hind all	max (lag)
SUR / WAV	0.6947	0.6947 (0)	0.7002	0.7002 (0)	0.7292	0.7292 (0)
SUR / DIS	0.1490	0.3030 (5)	0.0897	0.3208 (7)	0.0981	0.3283 (7)
WAV / DIS	0.1361	0.2724 (6)	0.1418	0.3683 (8)	0.1341	0.3630 (7)

Pretty well ...



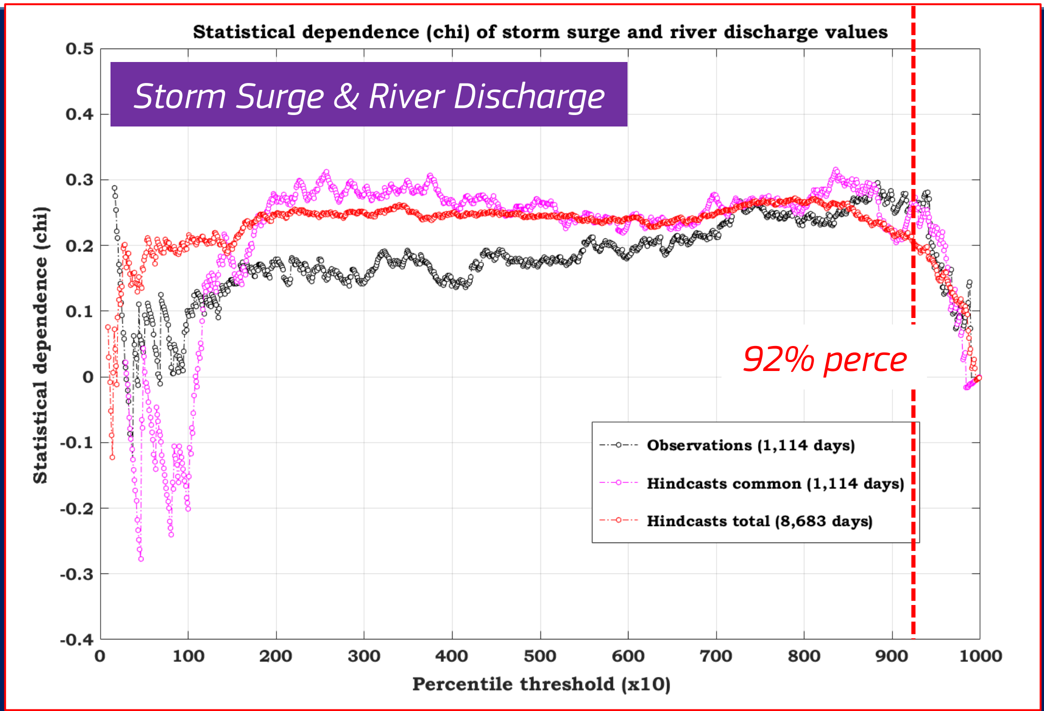


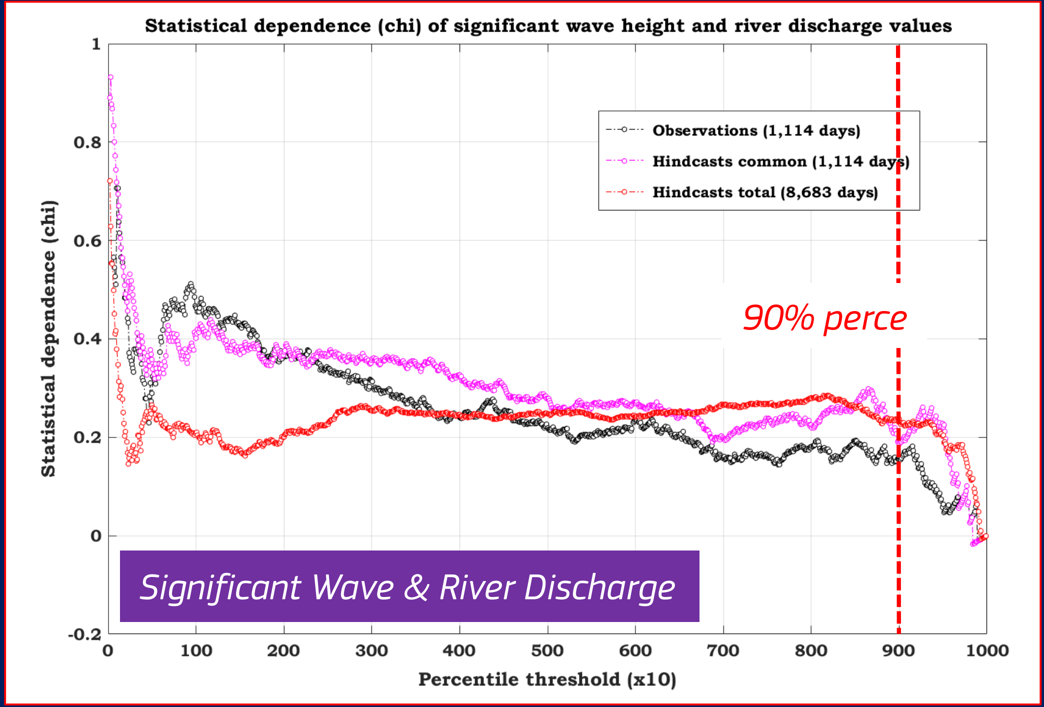
Surge Vs Wave in Obs / Hind Common / Hind Total Mode

	lead	thres	R (chiplot)	max	mat_chi	max (mat)	lag	R (taildep)	R max
obs	s / w	95%	0.6276	0.6276	0.5739	0.5739	0	0.5925	0.5925
hind_com	s / w	95%	0.5551	0.5551	0.5551	0.5551	0	0.5745	0.5745
hind_tot	s / w	95%	0.5683	0.5683	0.5712	0.5712	0	0.5850	0.5850

Storm Surge Vs Waves

Pretty well ...





How well Hindcasts resolve Dependencies (cont.)

Storm Surge & River Discharge in all Modes

	lead	thres	R (chiplot)	max	mat_chi	max (mat)	lag	R (taildep)	R max
obs	s / d	92%	0.1798	0.2939	0.1430	0.2571	6	0.2020	0.3161
hind	s / d	92%	0.0815	0.2444	0.0874	0.2503	6	0.1571	0.3200
total	s / d	92%	0.0897	0.2272	0.0754	0.2129	6	0.1468	0.2843

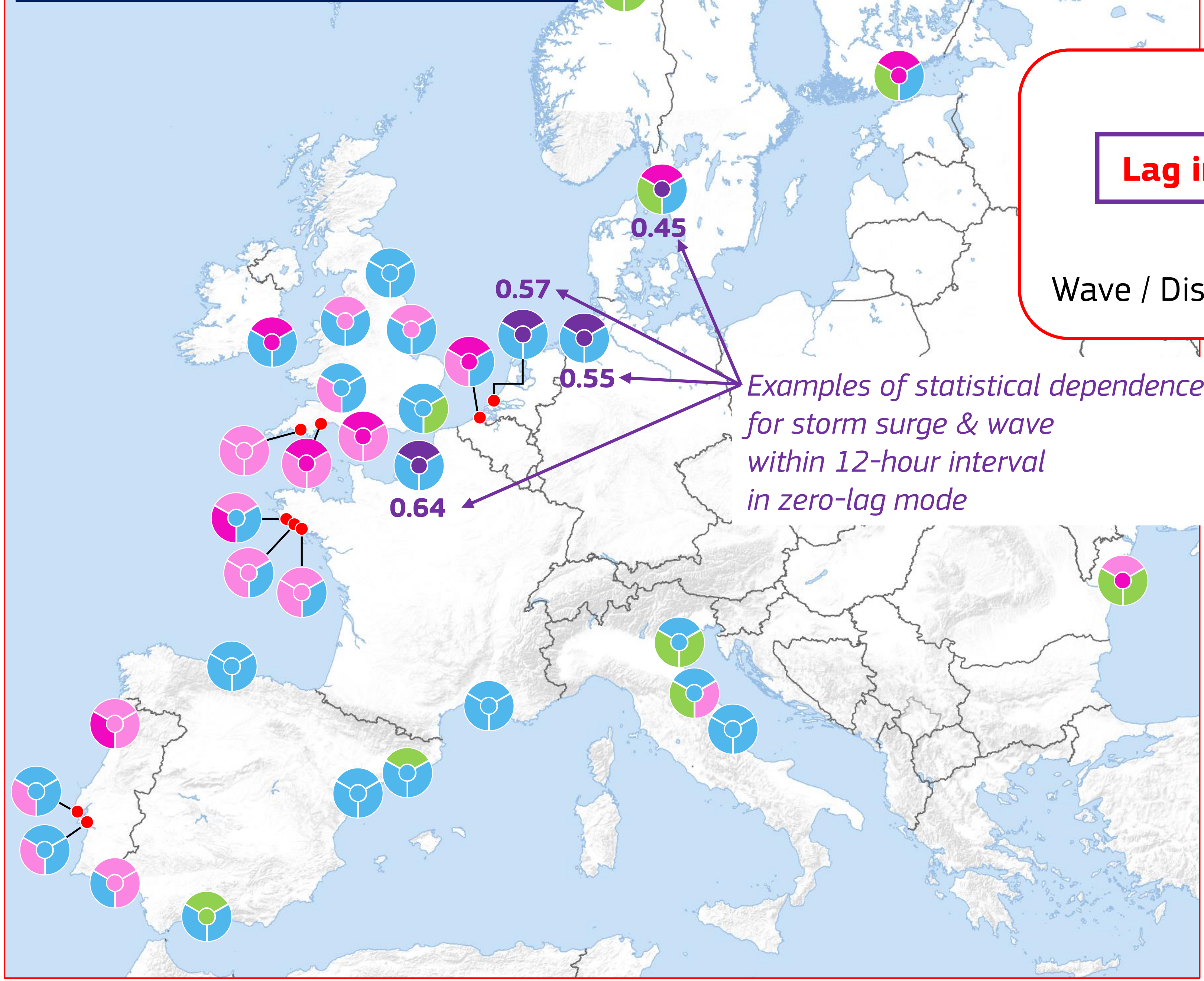
→ *Storm surge and river discharge hindcasts exhibit* ***almost identical*** *(max-lag) values of statistical dependence with observations*

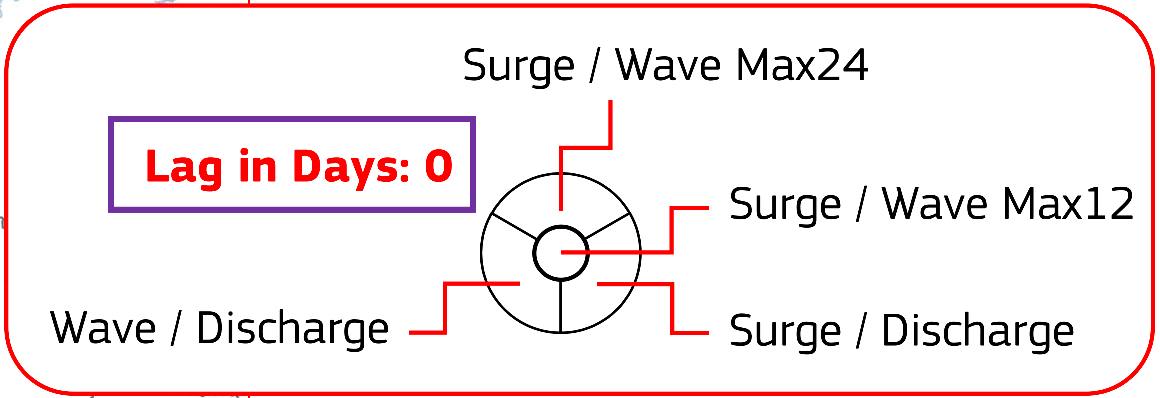
Significant Wave & River Discharge in all Modes

	lead	thres	R (chiplot)	max	mat_chi	max (mat)	lag	R (taildep)	R max
obs	w / d	90%	0.0996	0.2145	0.0427	0.1576	6	0.1346	0.2495
hind	w / d	90%	0.1001	0.2972	0.0310	0.2281	8	0.1346	0.3317
total	w / d	90%	0.0900	0.2544	0.0823	0.2467	7	0.1704	0.3348

→ *Significant wave and river discharge hindcasts exhibit* ***similar*** *(max-lag) values of statistical dependence with observations*

Dependencies of All Categories





Adaptation of Svensson & Jones, 2003 Tables

	Dependence (chi)	Category
	chi ≤ -0.06	*Negative*
	-0.05 ≤ chi ≤ 0.05	*Zero*
	0.06 ≤ chi ≤ 0.14	*Low*
	0.15 ≤ chi ≤ 0.24	*Modest*
	0.25 ≤ chi ≤ 0.34	*Well*
	0.35 ≤ chi ≤ 0.44	*Strong*
	chi ≥ 0.45	*Very Strong*

Results: Dependencies in Zero LAG Mode

RIEN	River	Ocean / Sea	S / W12	S / W24	S / R24	W / R24
01	Po (IT)	Adriatic Sea	mod	mod	low	low
02	Metauro (IT)	Adriatic Sea	mod	mod	well	mod
03	Vibrata (IT)	Adriatic Sea	mod	mod	mod	mod
08	Rhone (FR)	Gulf of Lion	mod	mod	mod	mod
04	Foix (ES)	Balearic Sea	mod	low	mod	mod
05	Ebro (ES)	Balearic Sea	mod	mod	mod	mod
06	Velez (ES)	Alboran Sea	low	low	mod	mod
07	Sella (ES)	Bay of Biscay	mod	mod	mod	mod
10	Moros (FR)	Bay of Biscay	mod	well	mod	strong
11	Aven (FR)	Bay of Biscay	well	well	mod	well
12	Blavet (FR)	Bay of Biscay	well	well	mod	well
13	Owenavorragh (IE)	Irish Sea	strong	strong	mod	mod
21	Mersey (UK)	Irish Sea	well	well	mod	mod
20	Severn (UK)	Bristol Channel	mod	mod	mod	well
15	Orkla (NO)	Norwegian Sea	well	well	low	low
16	Vantaa (FI)	Baltic Sea	strong	strong	mod	low
22	Tyne (UK)	North Sea	mod	mod	mod	mod
27	Humber (UK)	North Sea	well	well	mod	mod
14	Goeta Aelv (SE)	North Sea	v. strong	strong	mod	low
17	Rhine (NL)	North Sea	v. strong	v. strong	mod	mod
18	Weser (DE)	North Sea	v. strong	v. strong	mod	mod
19	Schelde (BE)	North Sea	strong	strong	mod	~well
25	Thames (UK)	North Sea	mod	mod	low	mod
09	Bethune (FR)	English Channel	v. strong	v. strong	mod	mod
24	Avon (UK)	English Channel	strong	strong	well	well
26	Exe (UK)	English channel	~strong	strong	well	well
23	Tamar (UK)	English Channel	well	well	well	well
28	Danube (RO)	Black Sea	strong	well	low	low
31	Douro (PT)	Atlantic Ocean	well	well	well	strong
29	Tagus (PT)	Atlantic Ocean	mod	mod	mod	well
30	Sado (PT)	Atlantic Ocean	mod	mod	mod	well
32	Guadianna (ES)	Atlantic Ocean	well	well	mod	well

Results are presented by means of analytical tables and detailed maps referring to both correlation and dependence (χ) values being estimated over RIEN points

It is then straightforward to estimate the joint probability value as the inverse of the joint return period

$$T_{X,Y} = \sqrt{\frac{T_x \cdot T_y}{\chi^2}}$$

Results: Dependencies in Max LAG Mode

RIEN	River	Ocean / Sea	L	S / W12	L	S / W24	L	S / R24	L	W / R24
01	Po (IT)	Adriatic Sea	0	mod	0	mod	4	mod	3	mod
02	Metauro (IT)	Adriatic Sea	0	mod	0	mod	0	well	0	mod
03	Vibrata (IT)	Adriatic Sea	0	mod	0	mod	2	well	1	mod
08	Rhone (FR)	Gulf of Lion	0.5	mod	0	mod	4	well	2	mod
04	Foix (ES)	Balearic Sea	0	mod	0	low	1	mod	0	mod
05	Ebro (ES)	Balearic Sea	0	mod	0	mod	3	mod	>7	well
06	Velez (ES)	Alboran Sea	0	low	0	low	0	mod	0	mod
07	Sella (ES)	Bay of Biscay	0.5	mod	0	mod	1	mod	1	mod
10	Moros (FR)	Bay of Biscay	0	mod	0	well	0	mod	0	strong
11	Aven (FR)	Bay of Biscay	0	well	0	well	0	mod	3	strong
12	Blavet (FR)	Bay of Biscay	0	well	0	well	0	mod	1	strong
13	Owenavorragh (IE)	Irish Sea	0	strong	0	strong	2	mod	3	mod
21	Mersey (UK)	Irish Sea	0	well	0	well	2	mod	1	mod
20	Severn (UK)	Bristol Channel	0	mod	0	mod	3	well	3	well
15	Orkla (NO)	Norwegian Sea	0	well	0	well	2	low	0	low
16	Vantaa (FI)	Baltic Sea	0	strong	0	strong	0	mod	2	mod
22	Tyne (UK)	North Sea	0.5	mod	0	mod	0	mod	0	mod
27	Humber (UK)	North Sea	0	well	0	well	0	mod	1	mod
14	Goeta Aelv (SE)	North Sea	0.5	v. strong	1	strong	1	mod	2	mod
17	Rhine (NL)	North Sea	0	v. strong	0	v. strong	4	well	5	well
18	Weser (DE)	North Sea	0	v. strong	0	v. strong	6	well	6	well
19	Schelde (BE)	North Sea	0	strong	0	strong	1	mod	2	well
25	Thames (UK)	North Sea	1	well	1	mod	0	low	1	mod
09	Bethune (FR)	English Channel	0	v. strong	0	v. strong	4	well	3	well
24	Avon (UK)	English Channel	0	strong	0	strong	2	well	3	well
26	Exe (UK)	English channel	0	~strong	0	strong	0	well	1	well
23	Tamar (UK)	English Channel	0	well	0	well	0	well	0	well
28	Danube (RO)	Black Sea	0.5	strong	0	well	>7	mod	0	low
31	Douro (PT)	Atlantic Ocean	0	well	0	well	1	well	1	strong
29	Tagus (PT)	Atlantic Ocean	0.5	mod	0	mod	>7	well	4	well
30	Sado (PT)	Atlantic Ocean	0	mod	0	mod	3	well	4	strong
32	Guadianna (ES)	Atlantic Ocean	0	well	0	well	3	well	3	~strong

Going After High-Impact Compound Events …

European Commission

Overall, besides the demonstration of how to apply **statistical dependence methodologies & techniques**

→ The highest values of (strong / very strong) correlations and dependencies were found **between surges and waves** mainly **over North Sea and English Channel** taking place on the same day (**zero-lag mode**)

→ **Moderate to well** category dependencies were found **for most sea areas**, also on a **zero-lag mode**

→ In the case of **surge and river discharge, moderate to well** category values were found in most cases but **NOT in a zero-lag mode** as in surge & wave case

→ It became clear that in order to achieve such (relatively high) values, **considerable lag time interval** of a few days was required with surge clearly leading discharge values

→ For the case of **wave and river discharge, well to strong** category values were found but once more mostly **in NON-zero lag mode** indicating the necessity of a considerable lag time interval for dependence to reach such (well / strong) values with wave distinctly leading discharge values

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