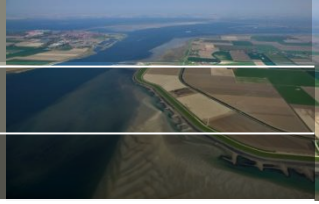
Deltares
Enabling Delta Life

Veranderingen in gemiddelde zeeniveaus in de Nederlandse kustwateren

Douwe Dillingh
Deltares

NCG workshop
Delft, 6 februari 2014

Inhoud



- Waarom is het belangrijk
- Hoe gaan we er mee om
- Wat meten we
- Trendanalyse
- Is er al een versnelling zichtbaar
- Resultaten
- Conclusies

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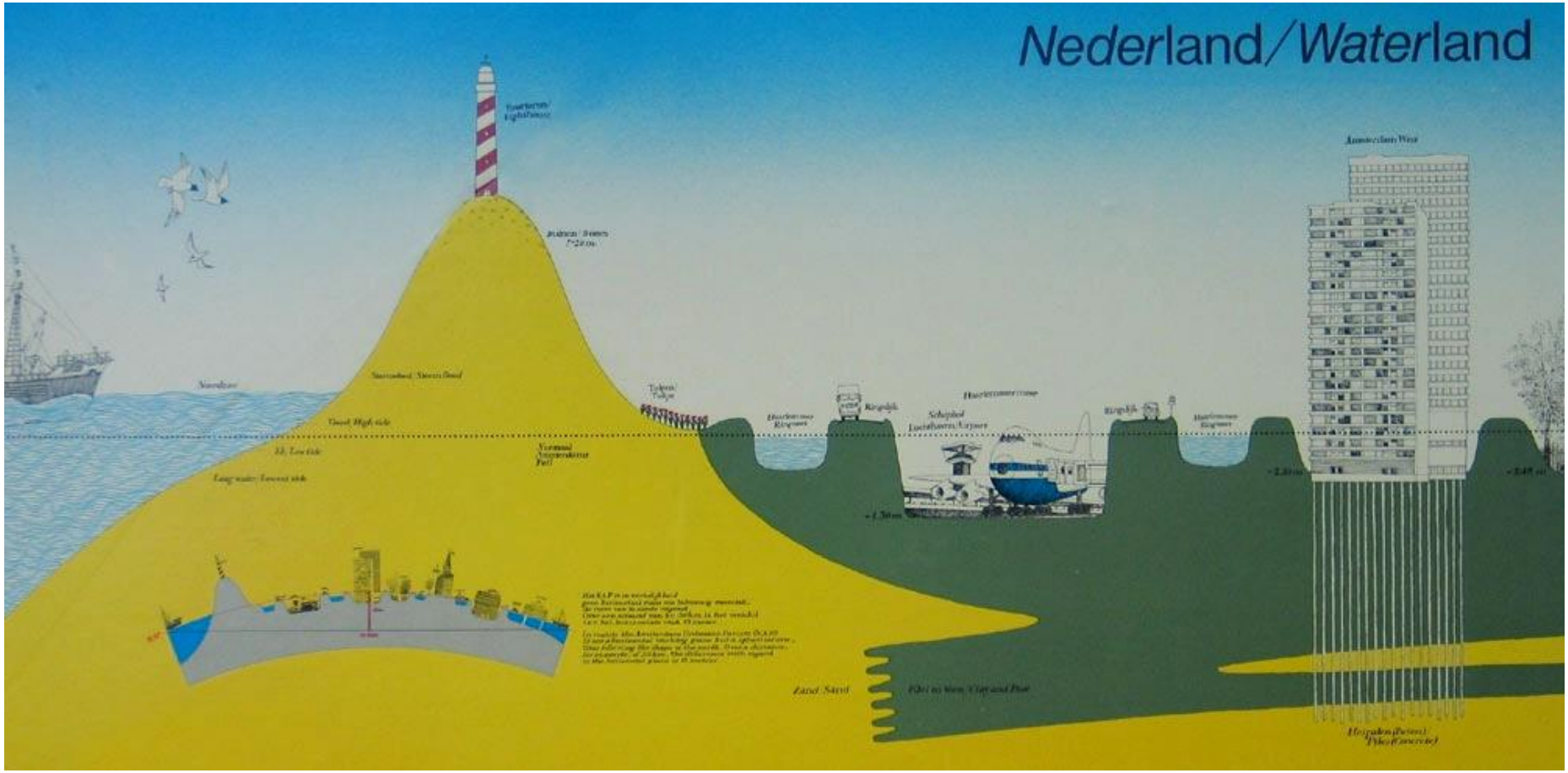
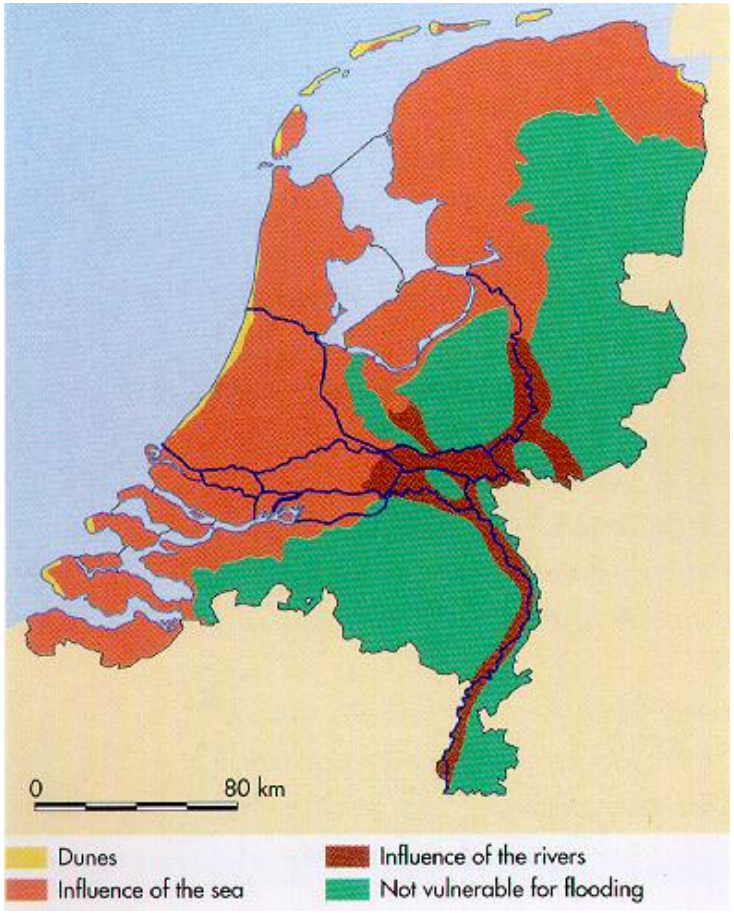
Veiligheid tegen overstromen



Kwetsbaar voor overstroming



1:2000

1:10000

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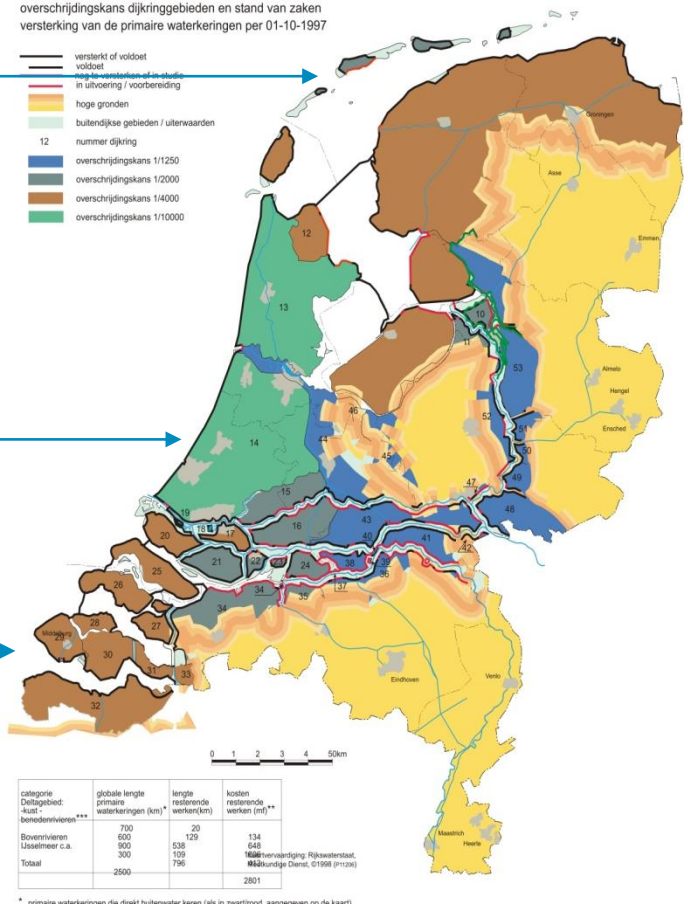
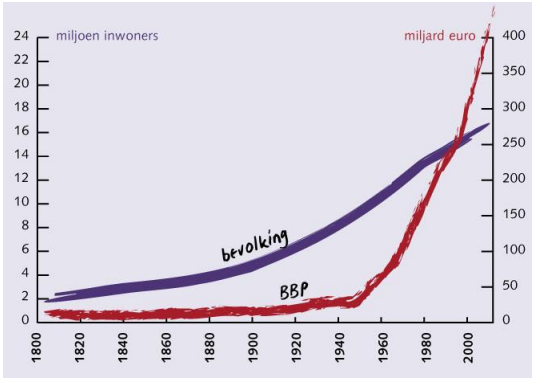
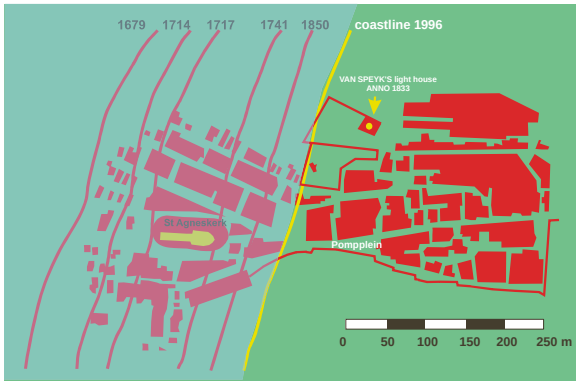
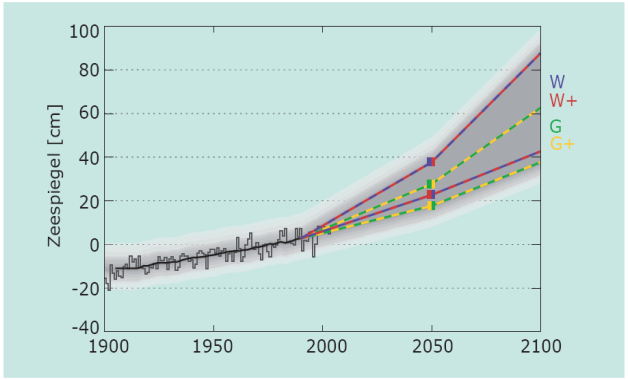


Druk op de kust

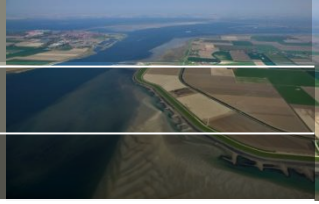
- Groeiende bevolking
- Toename investeringen
- Toename landgebruik
- Kusterosie
- Bodemdaling
- Zeespiegelstijging

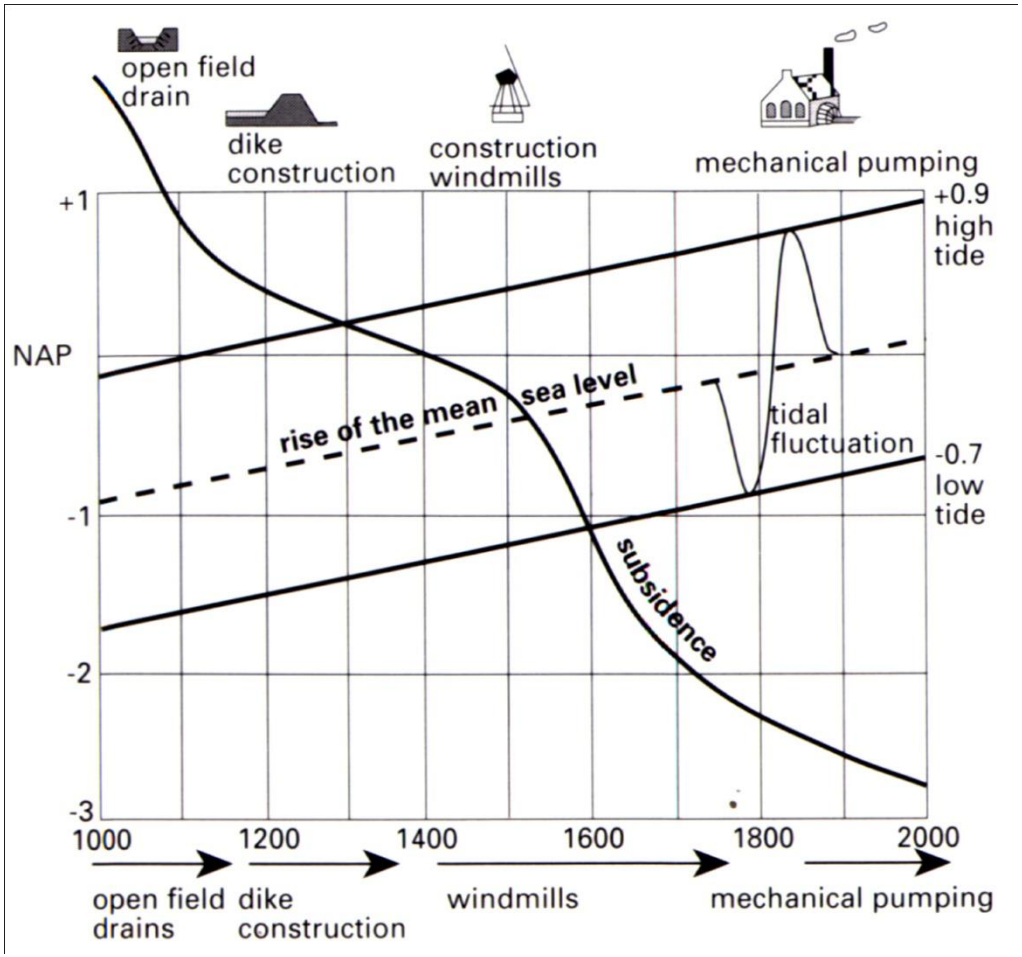






Bodemdaling maaiveld





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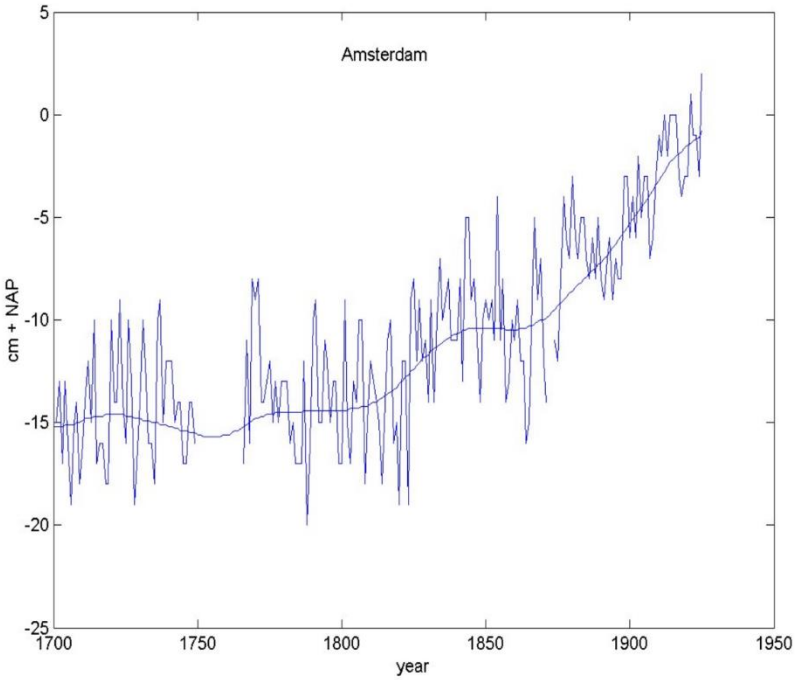
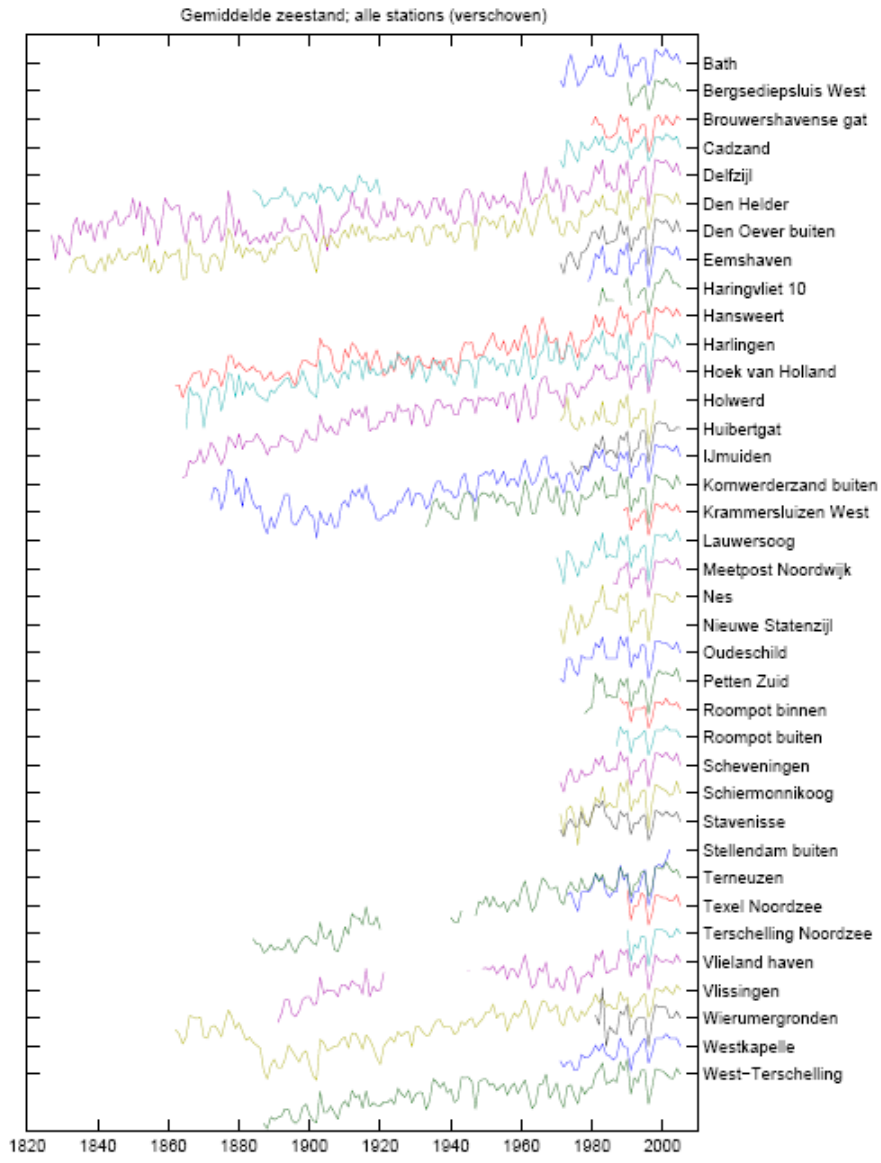
Zeespiegelstijging bestaat al lang

Kustlijn ca. 9000 BP

Verloop gemiddelde zeestand te Amsterdam (1700-1925)



Verloop gemiddelde zeestanden alle kuststations



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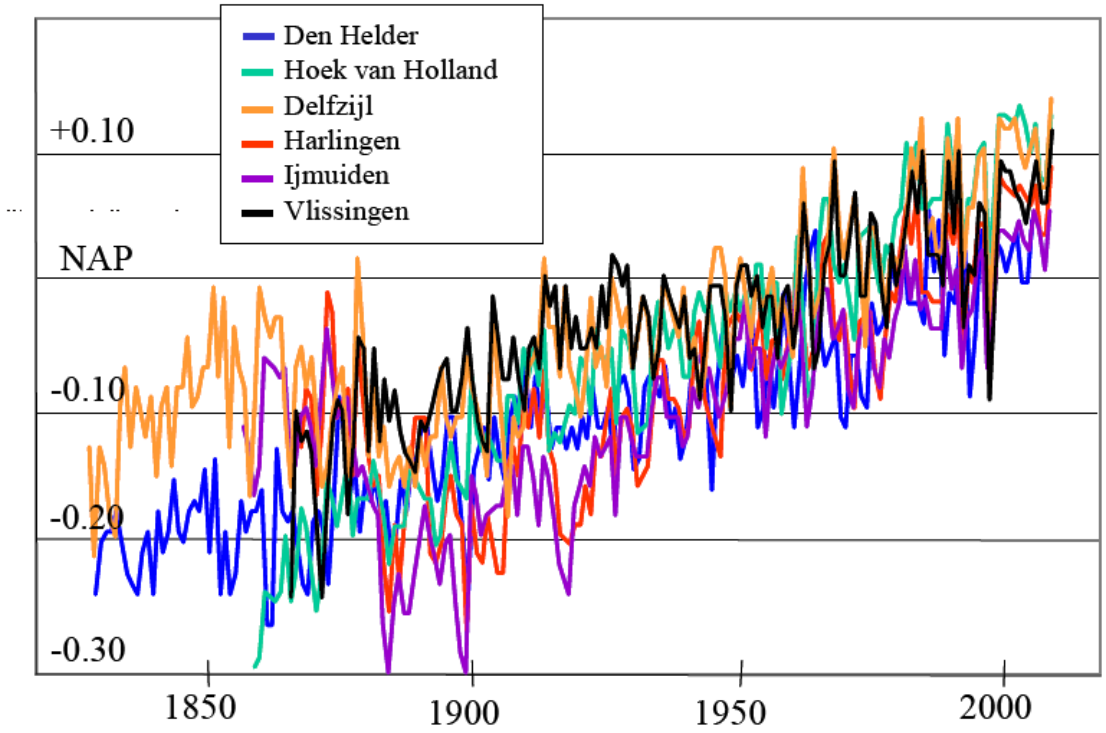
Verloop gemiddelde zeestanden 6 hoofdstations



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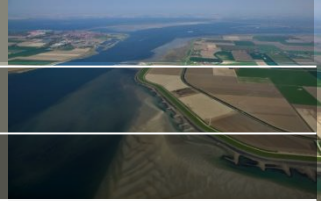
Oorzaken ruis op het meetsignaal



- Windklimaat Noordzee* / Noord-Atlantische Oceaan
- Luchtdruk*
- 18,6-jarige cyclus*
- Watertemperatuur
- Zoutgehalte
- Rivierafvoer
- Meetfouten
- Gegevensverwerking
- Aansluiting op het NAP

De belangrijkste zijn aangegeven met een *

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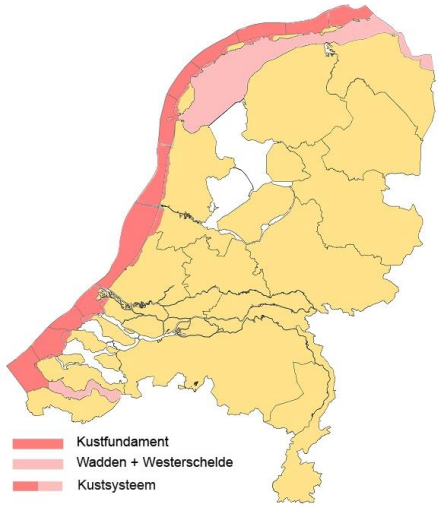
Huidige kust- en veiligheidsbeleid

- Dynamisch handhaven van de kustlijn en door suppleties de kust mee laten groeien met de zeespiegelstijging
- Duurzaam kustfundament, handhaving zandbalans
- Zesjaarlijkse veiligheids-toetsing (Waterwet, 2009)
- Landwaarts reserveren van ruimte voor het opvangen van toegenomen belastingen als gevolg van zeespiegelstijging.

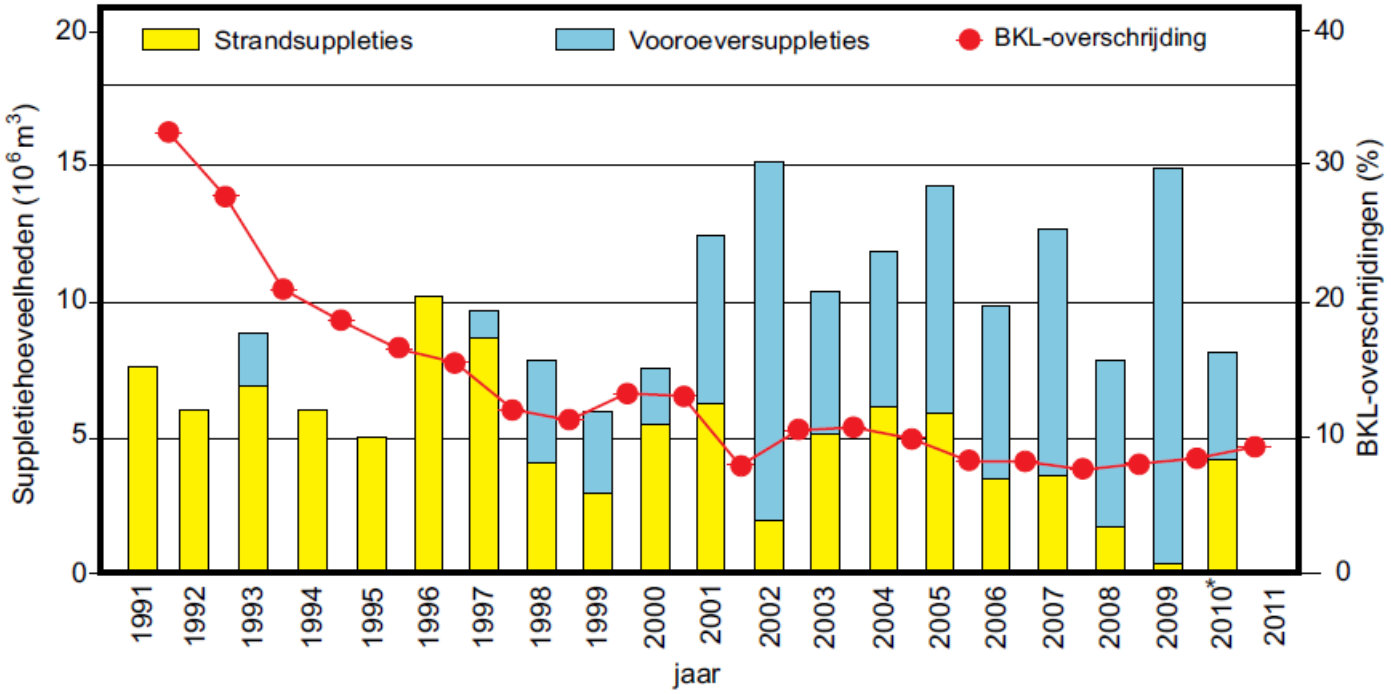


Kustfundament en kustsysteem

Meegroeien met de zeespiegel

Suppletiehoeveelheden en de basiskustlijn

BKL = Basiskustlijn = kustlijn in 1990



geel: **strandsuppleties**
blauw: **vooroeversuppleties**
rood: **percentage overschrijdingen van de BKL**

(Bron: Kustlijnkaartenboek 2011)

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Beleidscenario's voor toekomstige zss

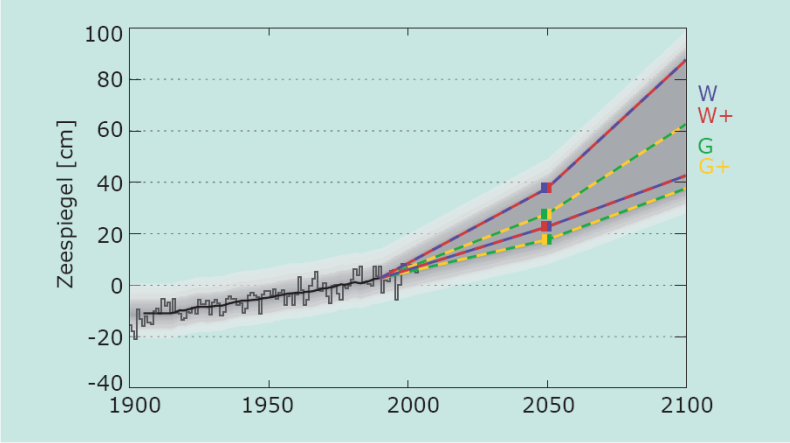
Minimum scenario van 20 cm per eeuw:
toepassen bij beslissingen met korte ontwerpduur (orde 5 jaar), geringe investering of hoge mate van flexibiliteit (zandsuppleties)

Middenscenario van 60 cm per eeuw:

Toepassen bij beslissingen met langere ontwerpduur (orde 50-100 jaar), grote investering en weinig flexibiliteit (dijken en stormvloedkeringen)

Maximum scenario van 85 cm per eeuw + 10% toename wind:

Toepassen bij reservering van ruimte voor toekomstige versterkingen (tijdhorizon 200 jaar)



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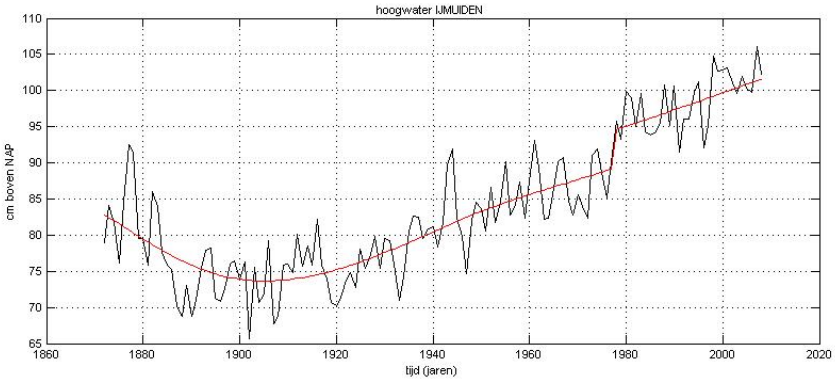
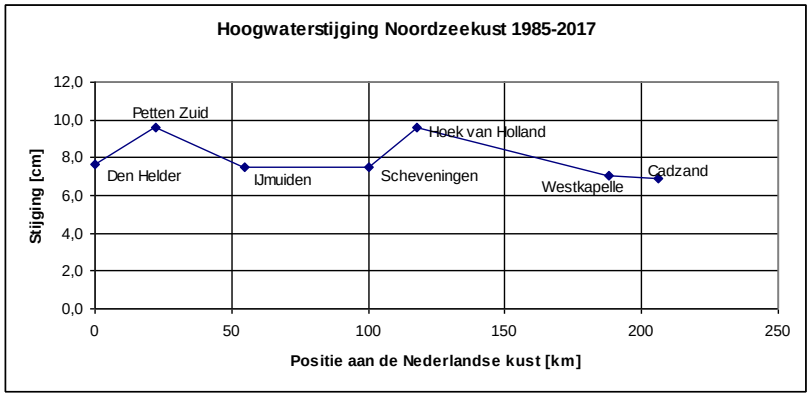
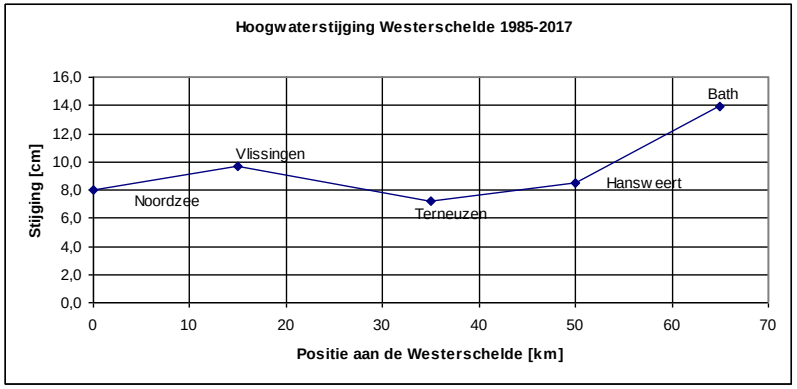
Veiligheid: Stijging gemiddeld hoogwater (1985 – 2017)

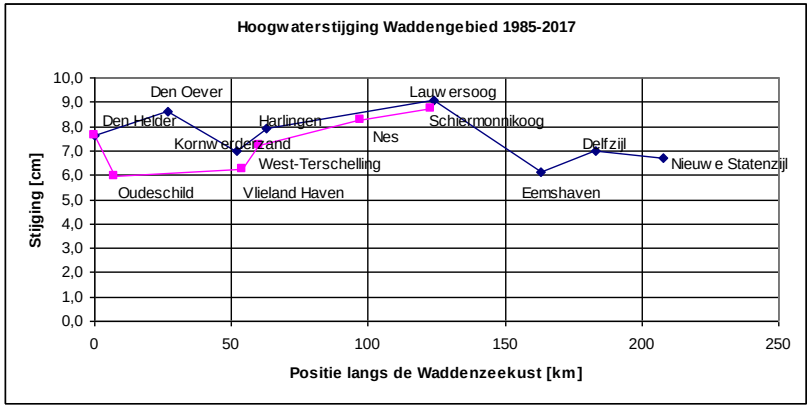




Keuze: overal 8 cm

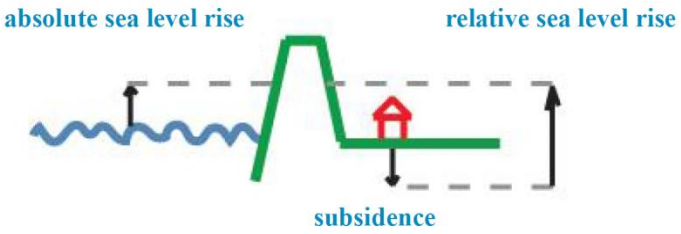


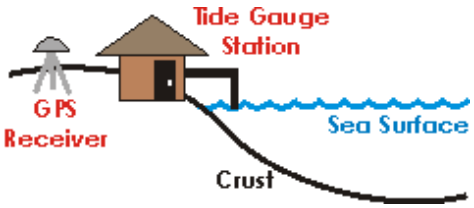
Keuze: tot Hansweert 8 cm,
daarna lineair toenemend tot 14 cm bij Bath

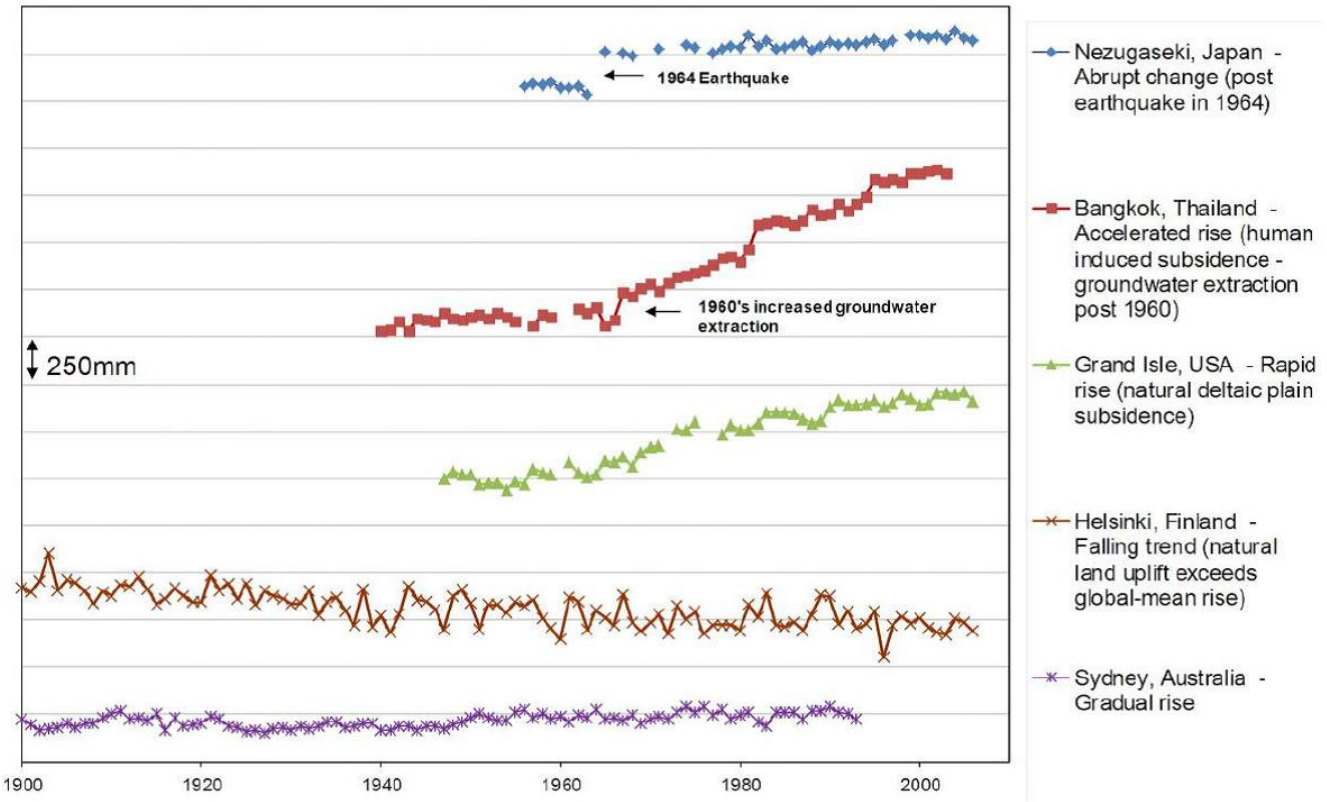


Keuze: 8 cm voor het Waddengebied,
7 cm voor de Eems-Dollard

Relatieve zss van peilmeetstations







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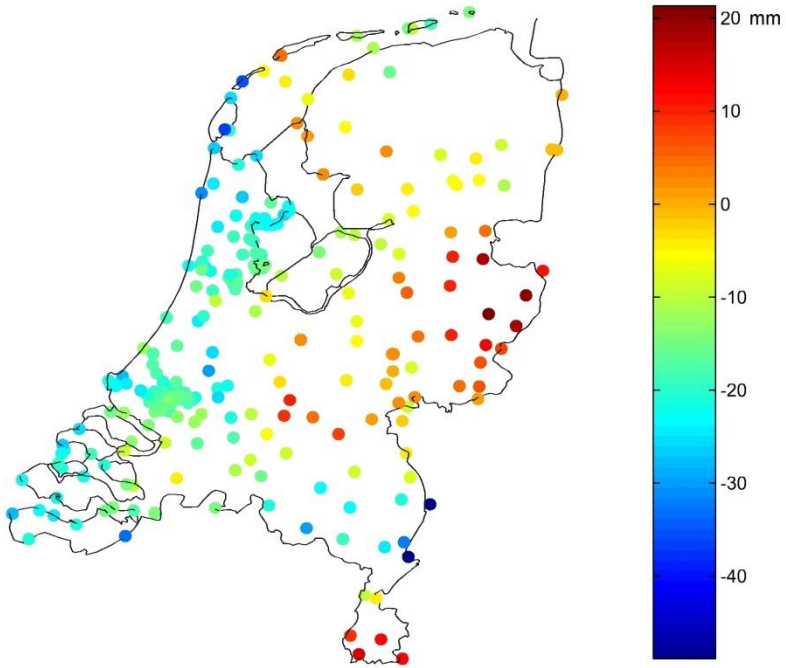
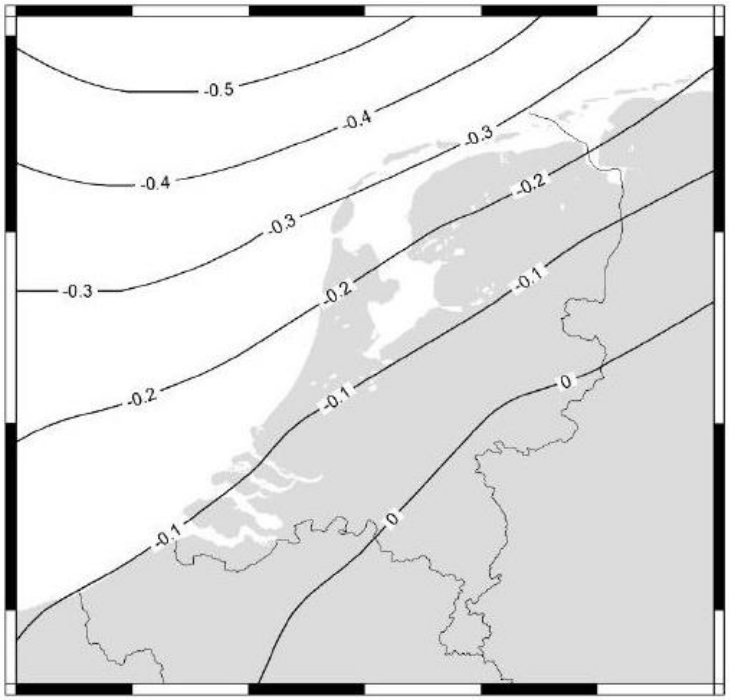
Hoogtewijzigingen primaire NAP-netwerk in 2005

Oorzaken autonome bodemdaling:
- **Isostasie**
- **Compactie**
- **Tektoniek**

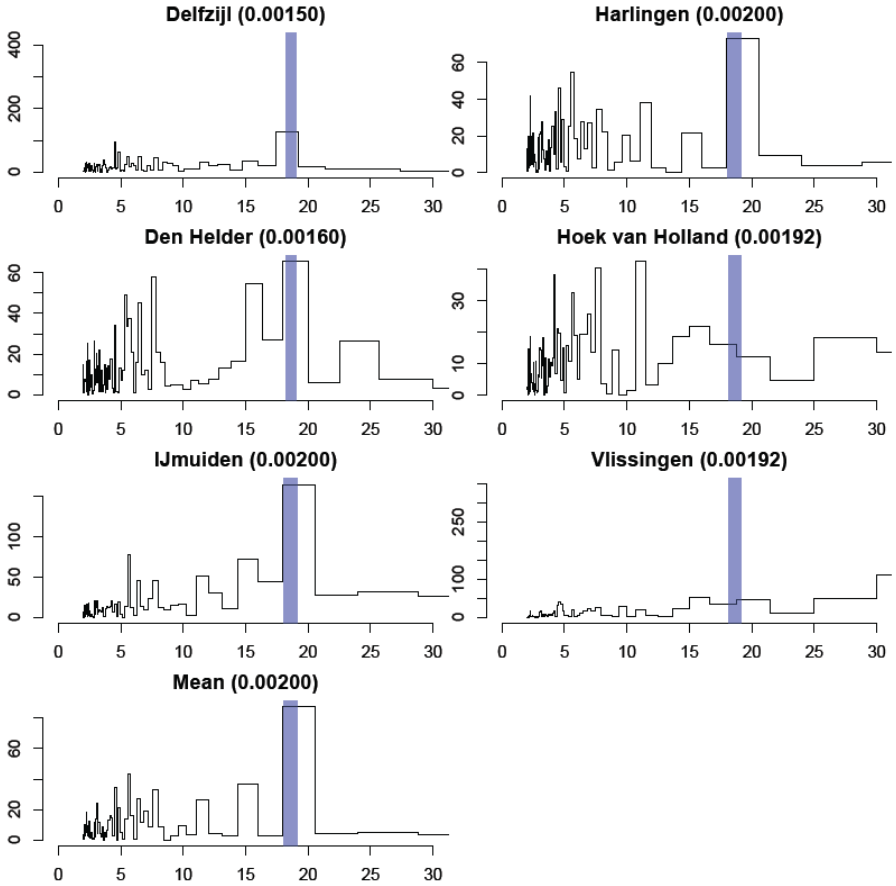


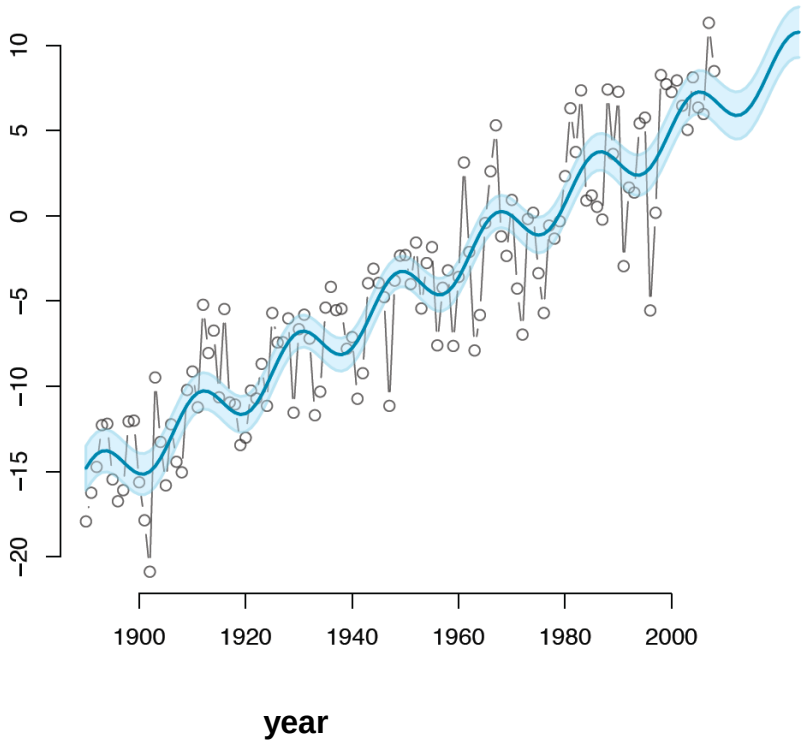
Glacial isostatic adjustment [mm/year] (from:Kooi et al., 1998)



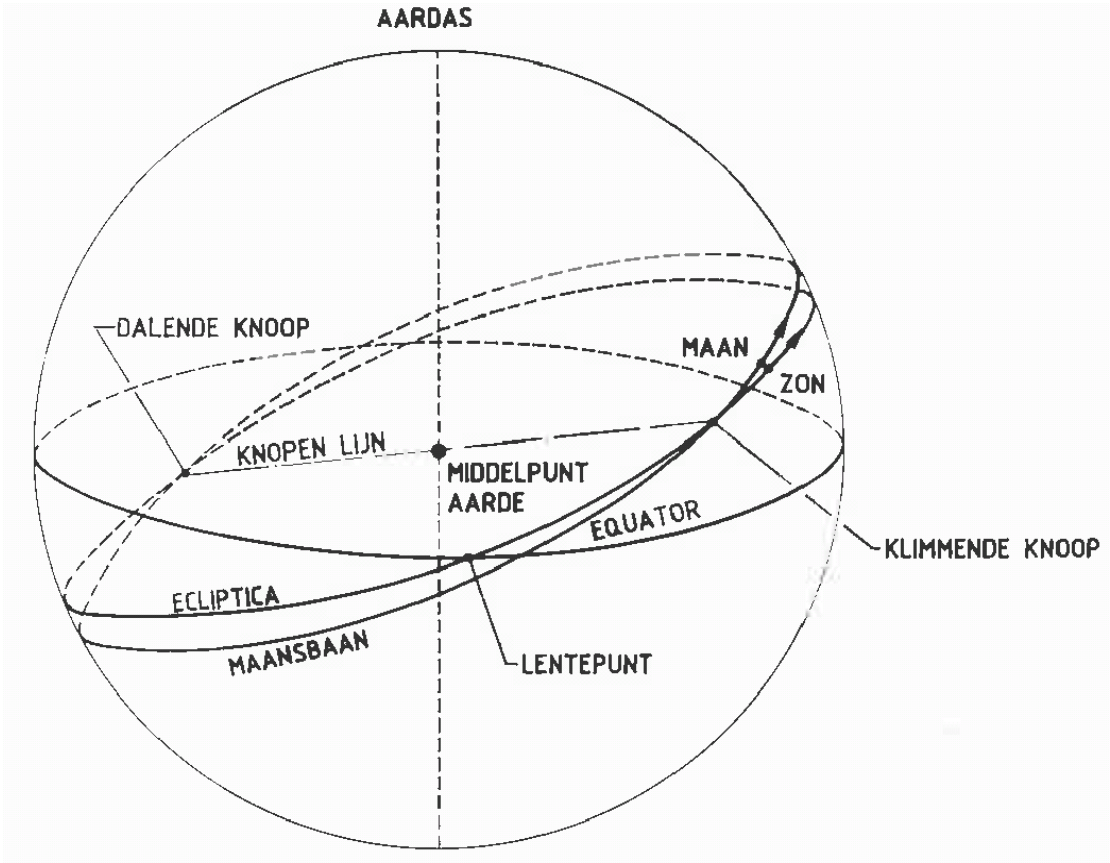
Spectrale analyse tijdreeksen gem. zeestand

Knopencyclus (18.6 years)



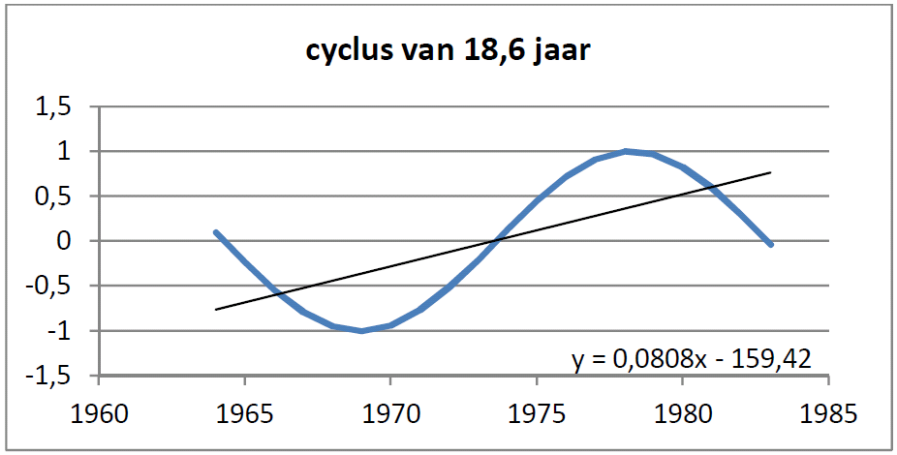


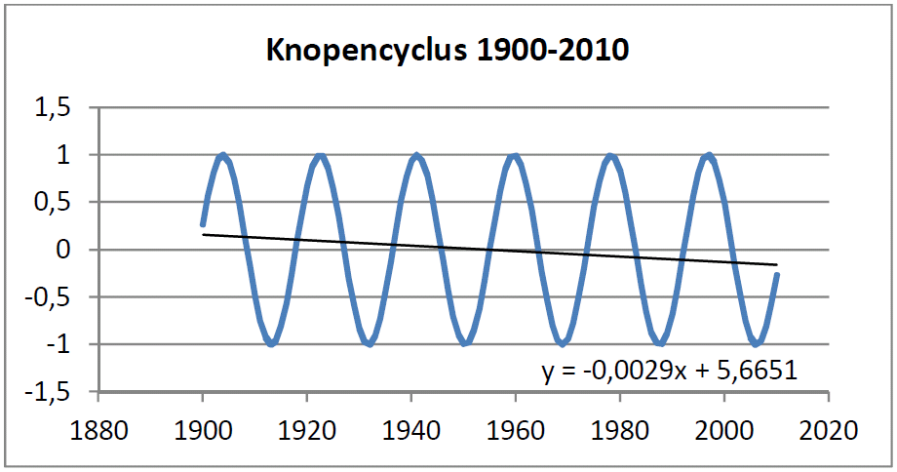
Oorsprong 18,6-jarige cyclus



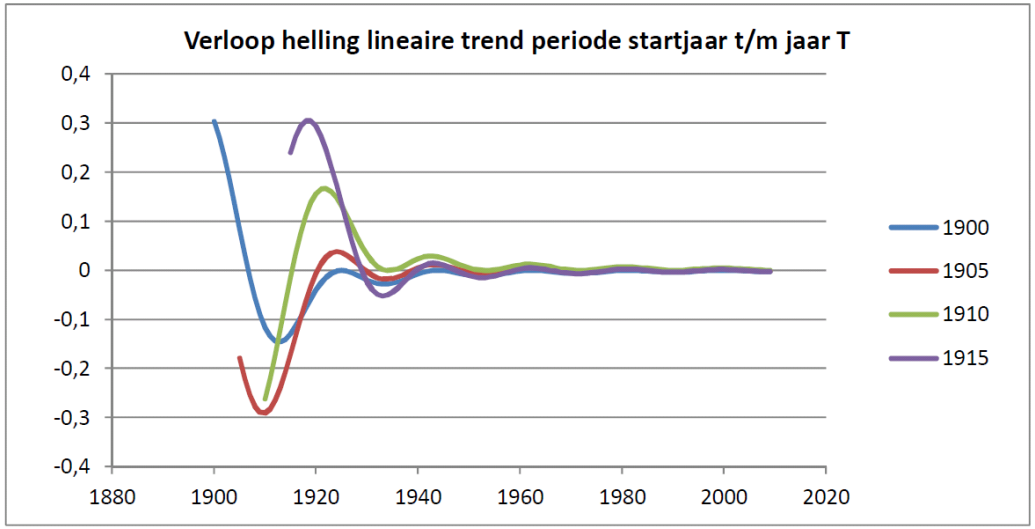
Snijcirkels gevormd door de doorsnijding van de vlakken van de equator, de ecliptica en de maansbaan met de hemelbol

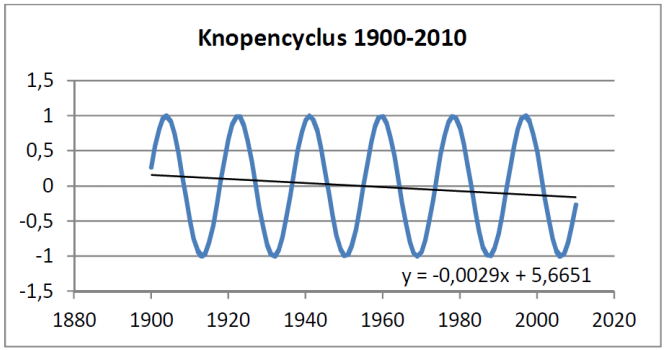
Lineare trend op een sinusoïde

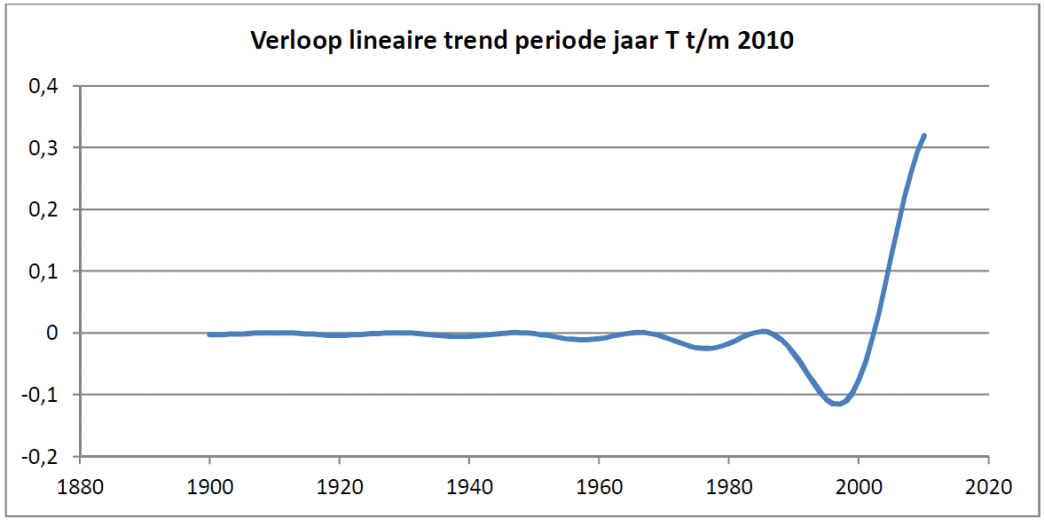




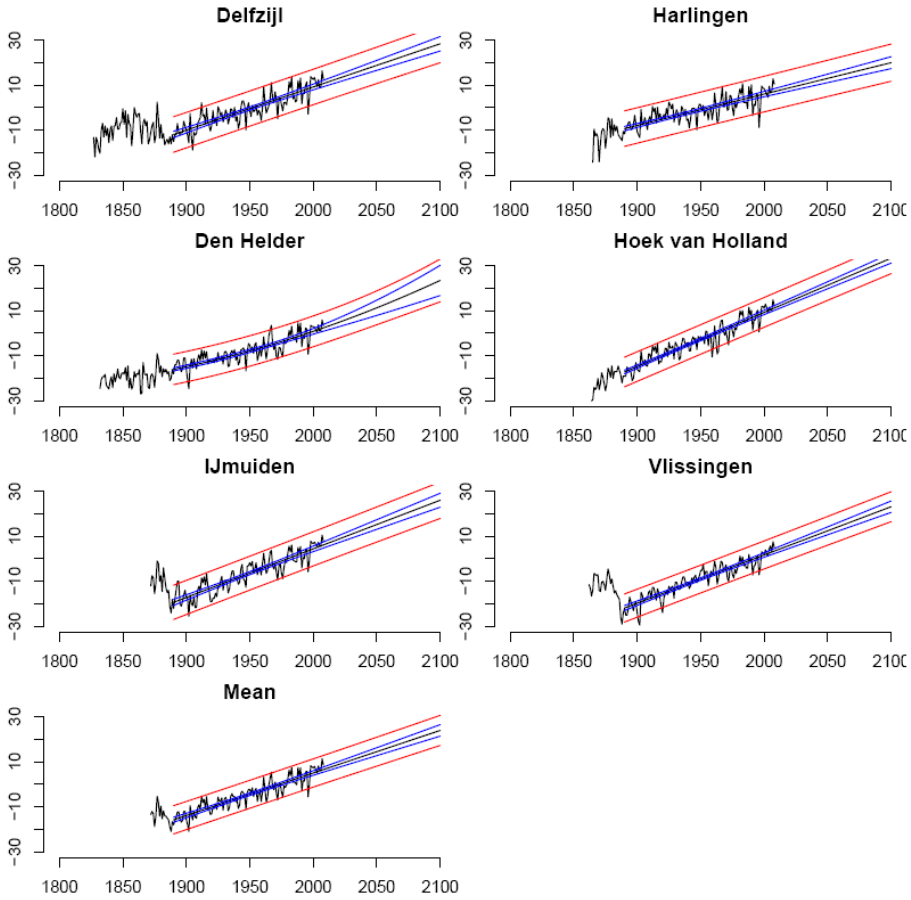
Lineare trend op een sinusoïde







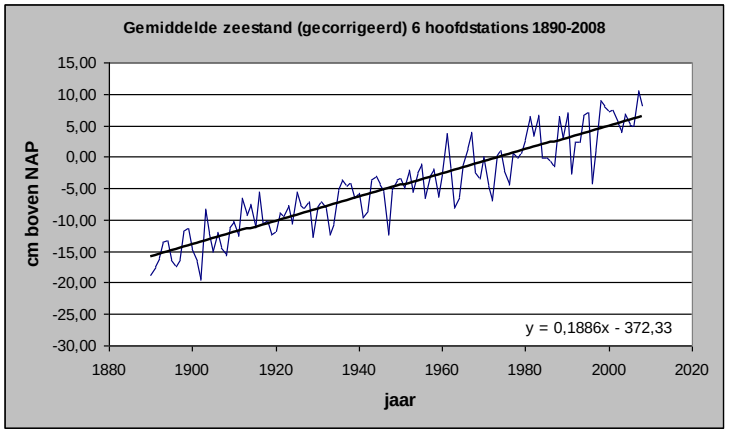
Lineare en kwadratische regressie-analyse



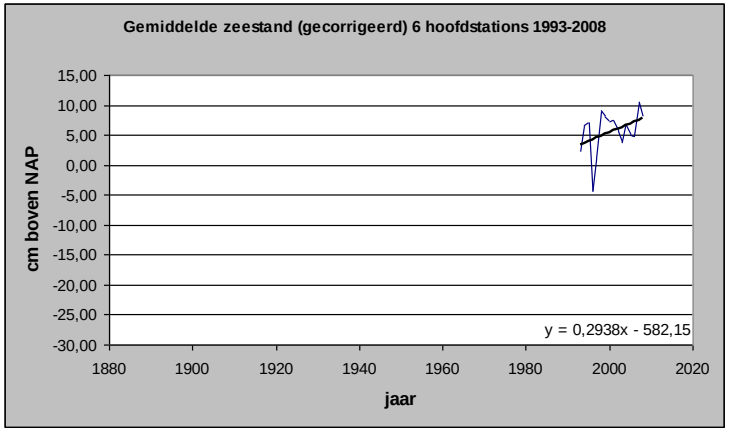
$$h = \beta_0 + \beta_1 t$$

$$h = \beta_0 + \beta_1 t + \beta_2 t^2$$

1890 - 2008



1993 - 2008



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Lineare trends verschillende analysis periodes

Station	1890-2008	1950-2008	1993-2008	1959-2008 last 50 years	1969-2008 last 40 years	1979-2008 last 30 years	1989-2008 last 20 years	1999-2008 last 10 years
Delfzijl	19	23	19	23	25	21	21	-15
Harlingen	13	16	43	15	15	12	36	12
Den Helder	15	18	22	20	27	15	19	3
IJmuiden	22	19	24	22	30	19	31	-3
Hoek van Holland	24	28	30	33	31	21	30	4
Vlissingen	21	17	38	20	26	26	39	38
Mean	**19**	**20**	**29**	**22**	**26**	**19**	**29**	**7**

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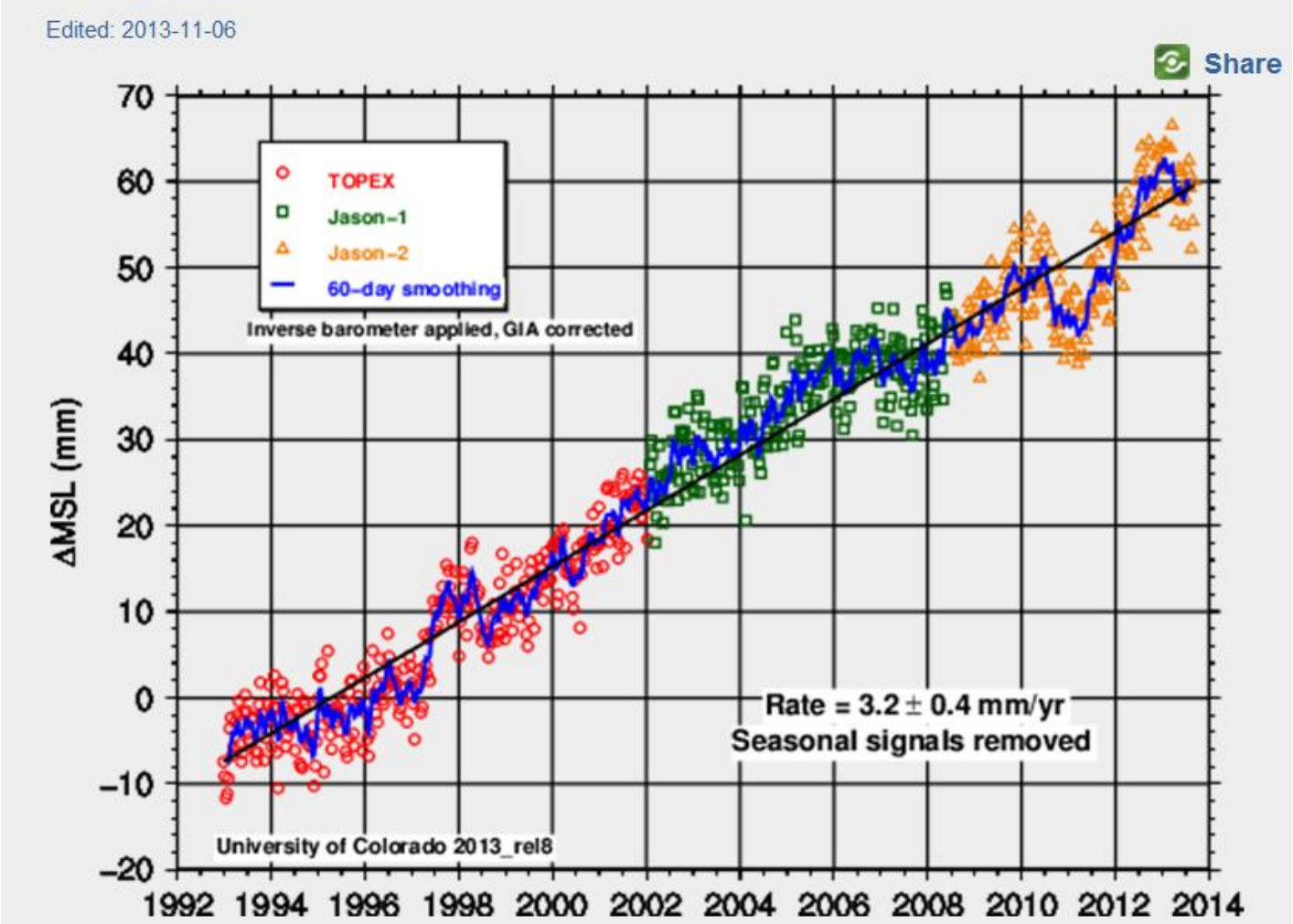
Satelliet data: mondiaal gemiddelde zeespiegel



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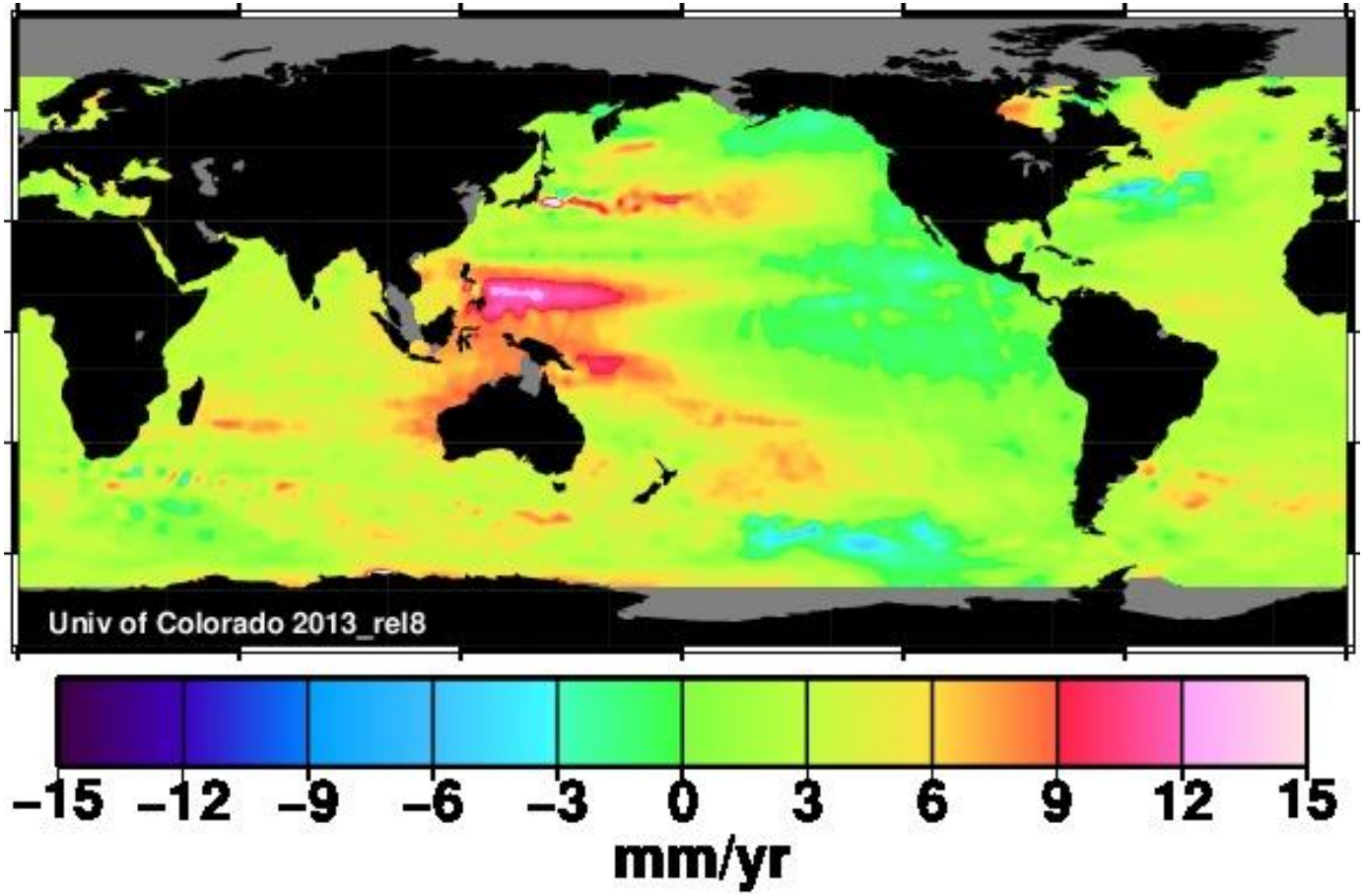
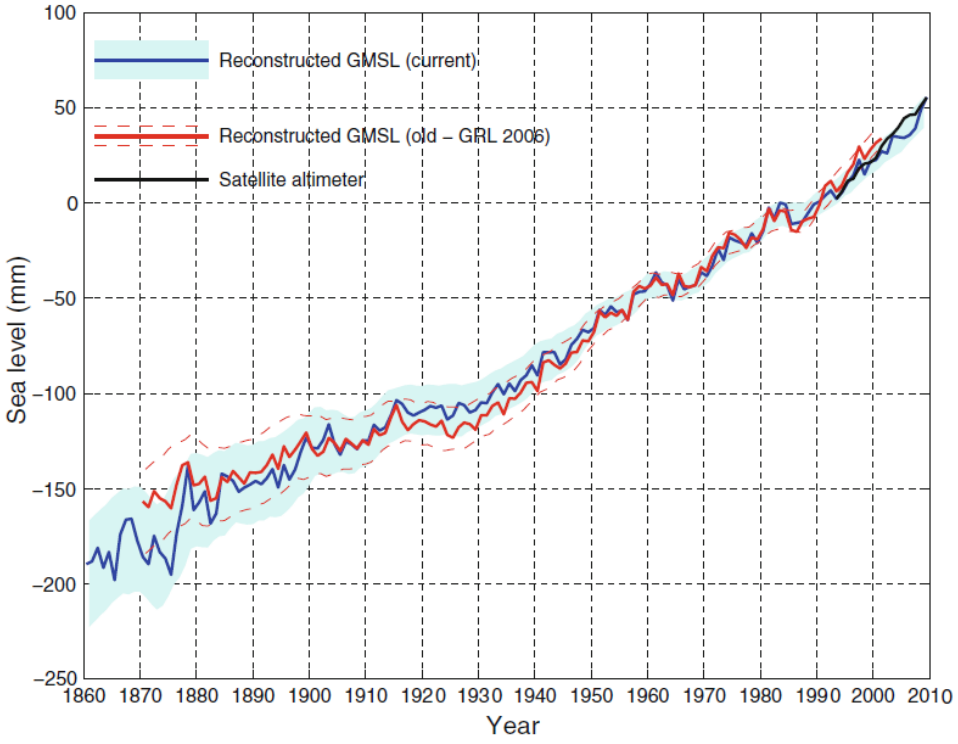
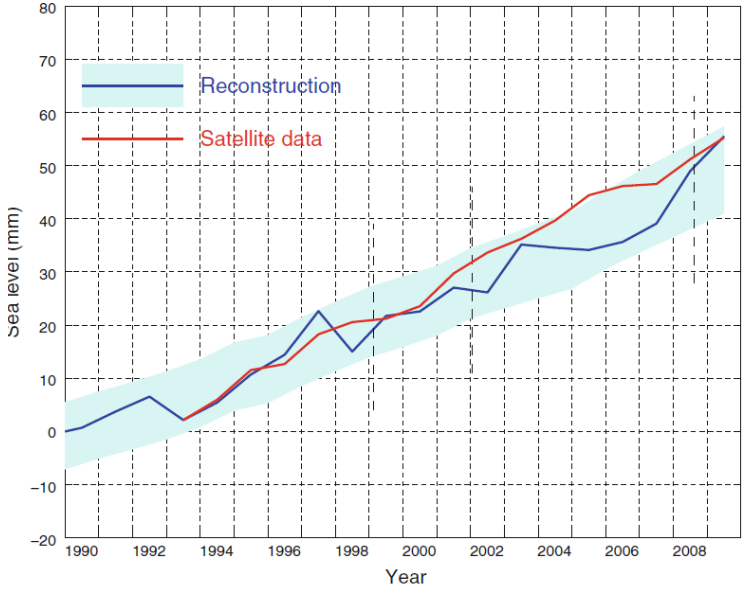
Geografische verdeling lineaire trend satellietdata



MGZSS volgens satellieten en peilmeetstations





(from: Sea-Level Rise from the Late 19th to the Early 21st Century, Church and White, Surv Geophys, 2011)

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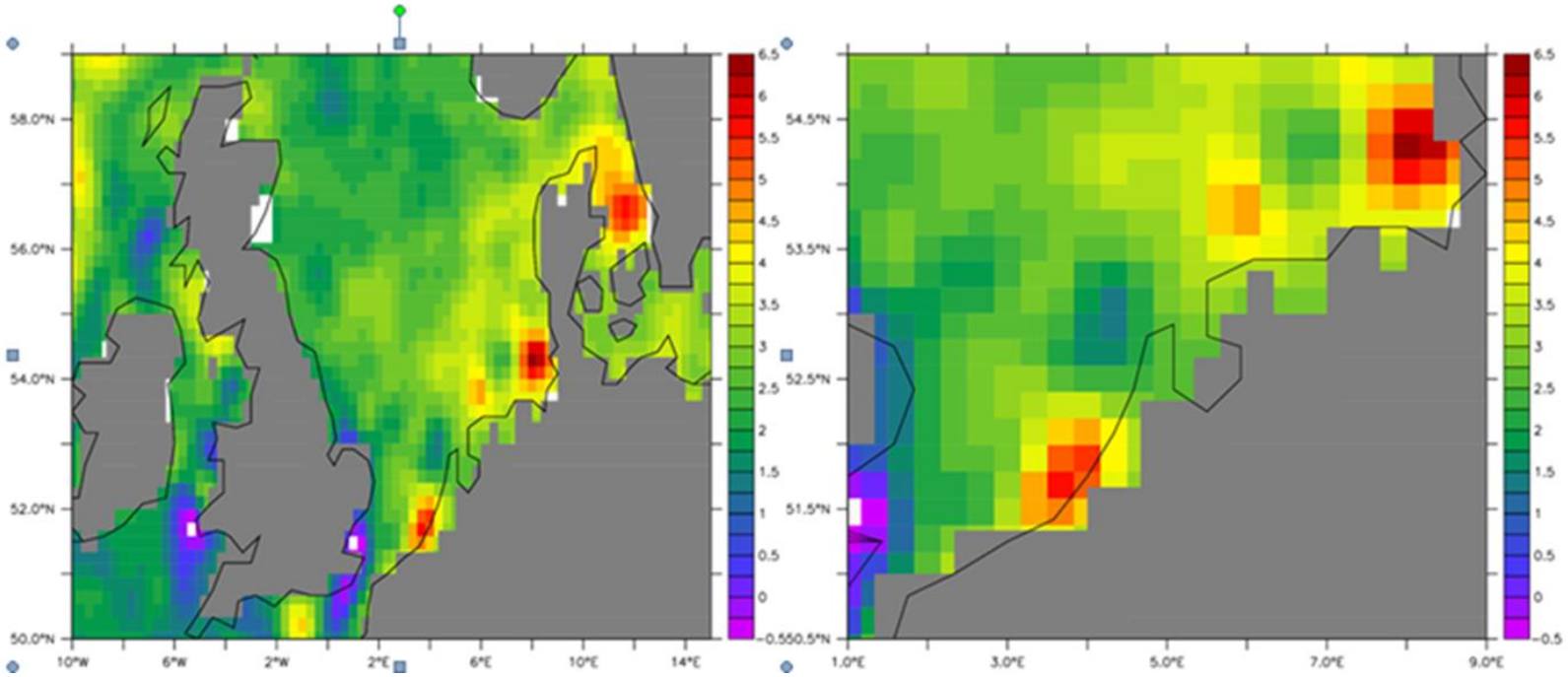
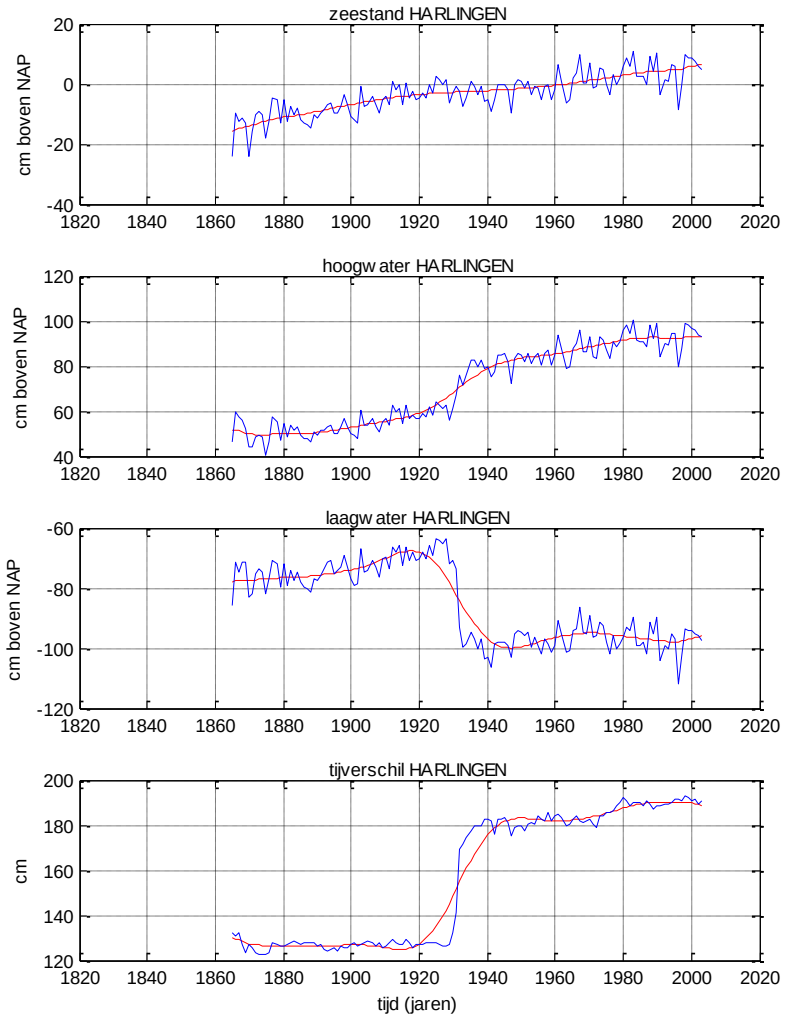
Satellietdata Noordzee 1993-2012

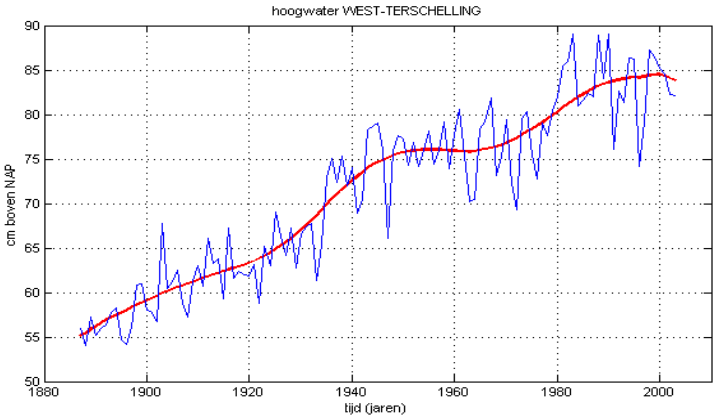


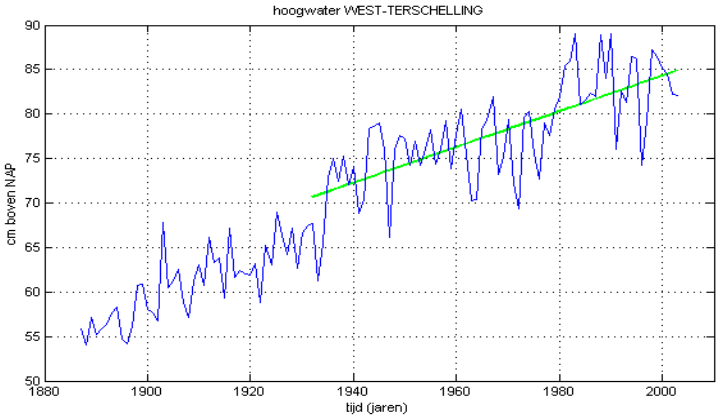
(Uit: Zeespiegelmonitor; John de Ronde (Deltares), Fedor Baart (Deltares),Vincent Vuik (DHV) Caroline Katsman (KNMI)

Niet-lineair: Singular Spectrum Analysis



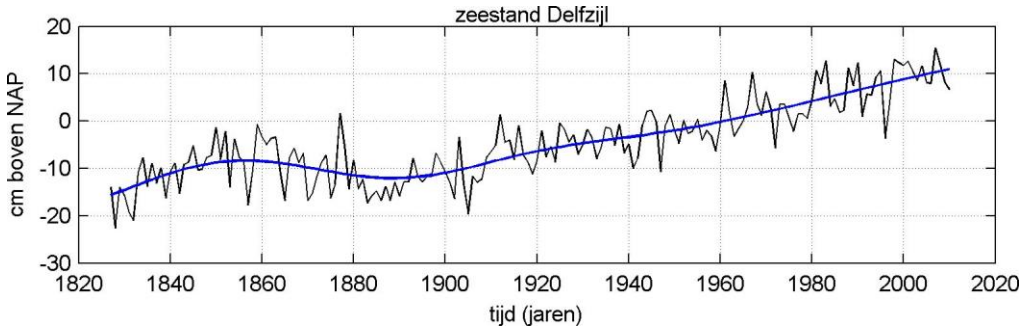
Mean high water West-Terschelling





Penalized Least Sum of Squares / Whittaker smoother

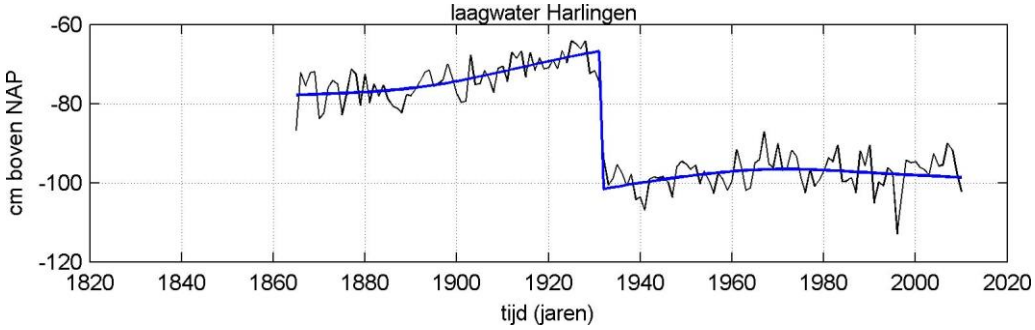
$$Q = \sum_i w_i (y_i - z_i)^2 + \lambda \sum_i (\Delta^2 z_i)^2.$$

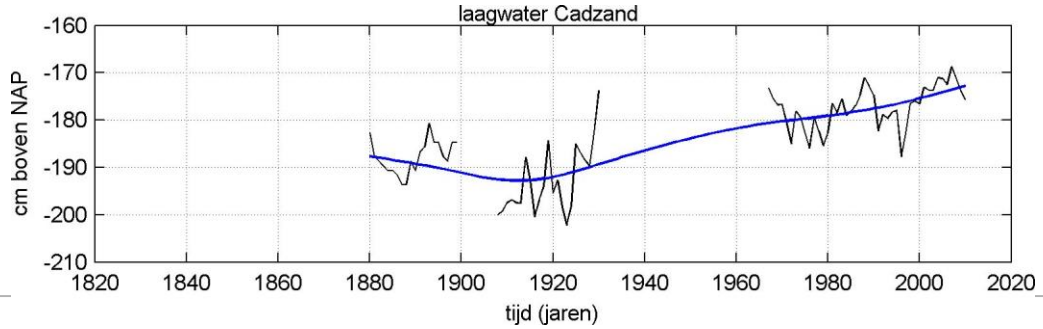


Gemiddelde zeespiegel Delfzijl

($\lambda = 10^4$)

Gemiddeld laagwater Harlingen





Gemiddeld laagwater Cadzand

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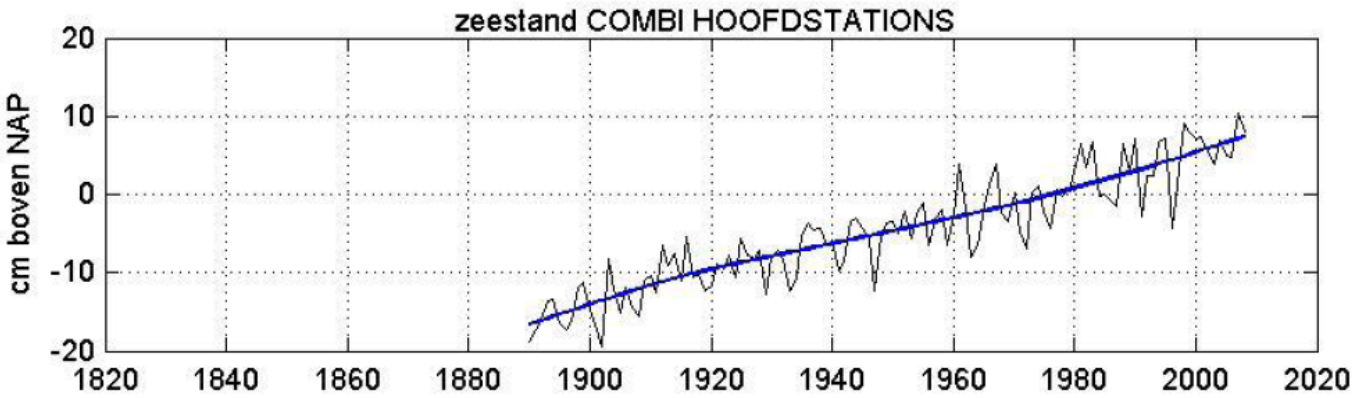
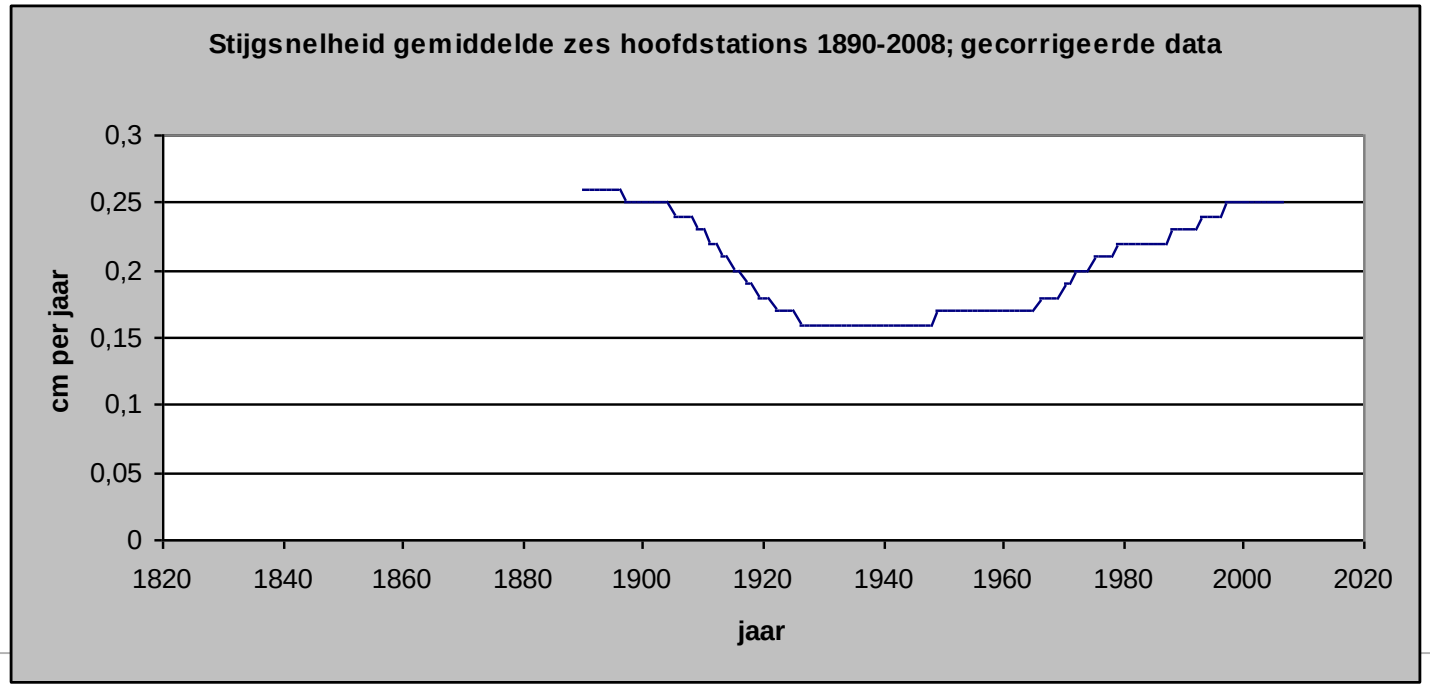
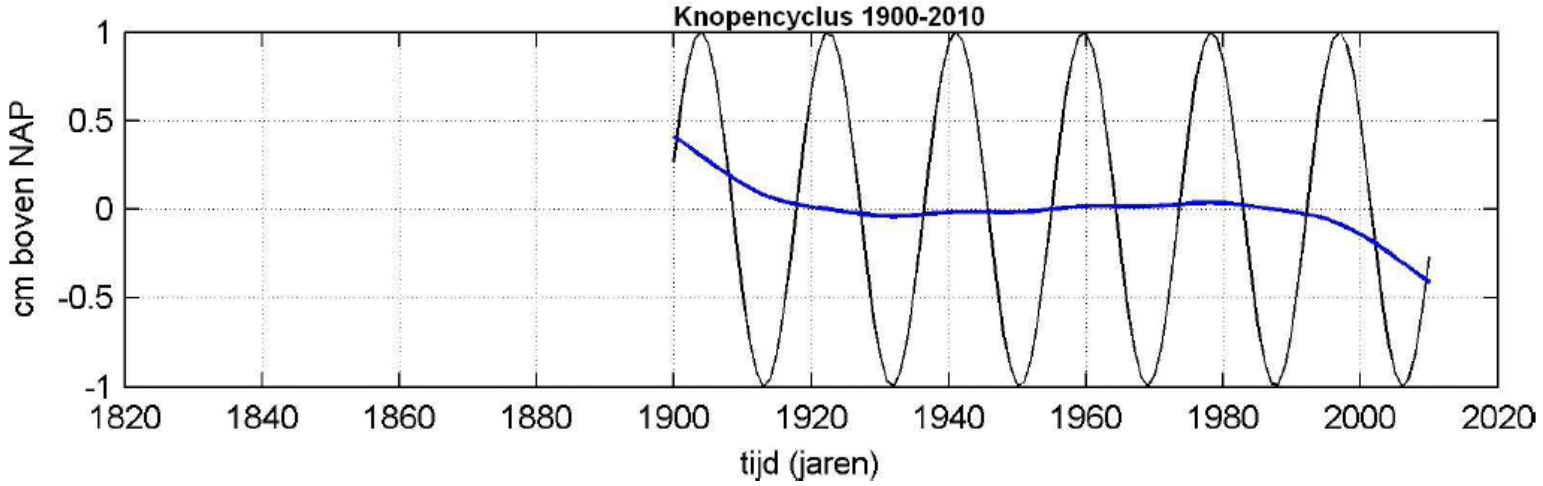
Penalized Least Sum of Squares (PLSS); $\lambda = 10^4$

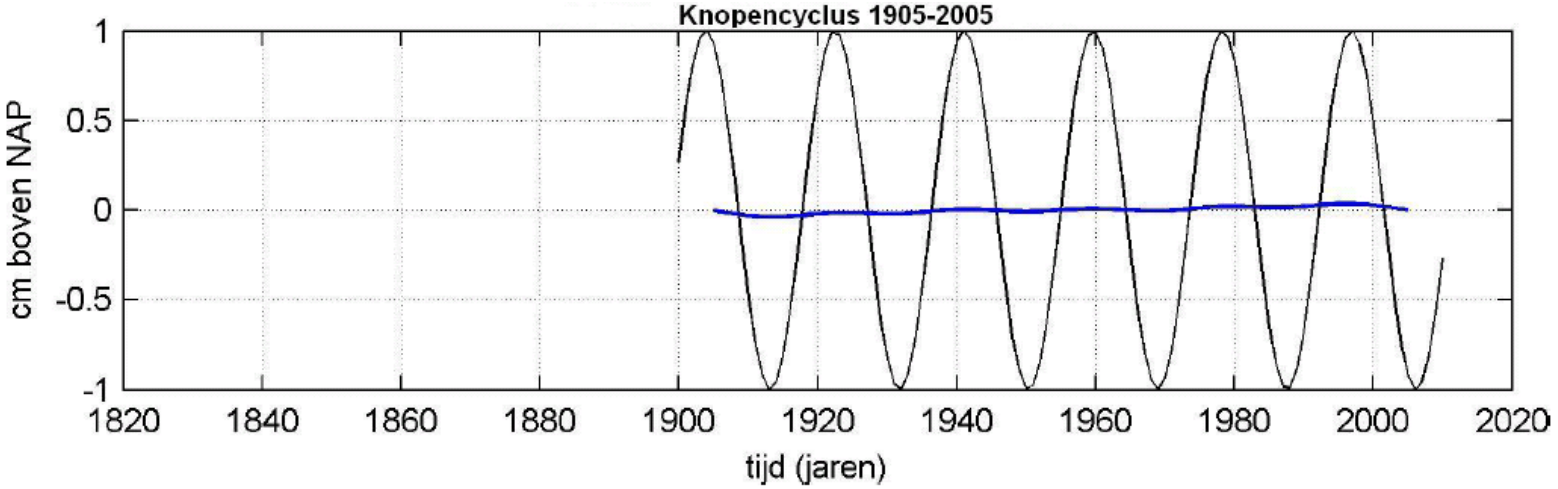




Deltares

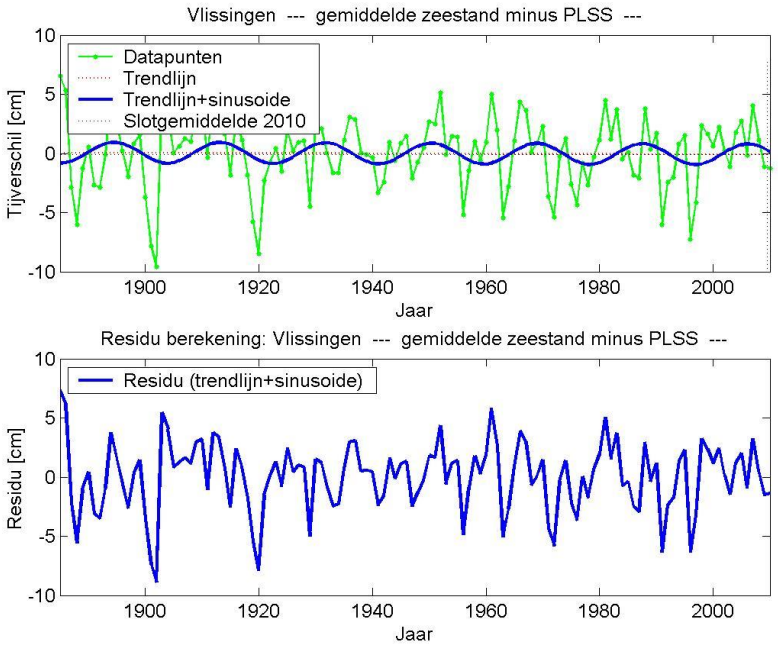
PLSS-trend en de knopencyclus



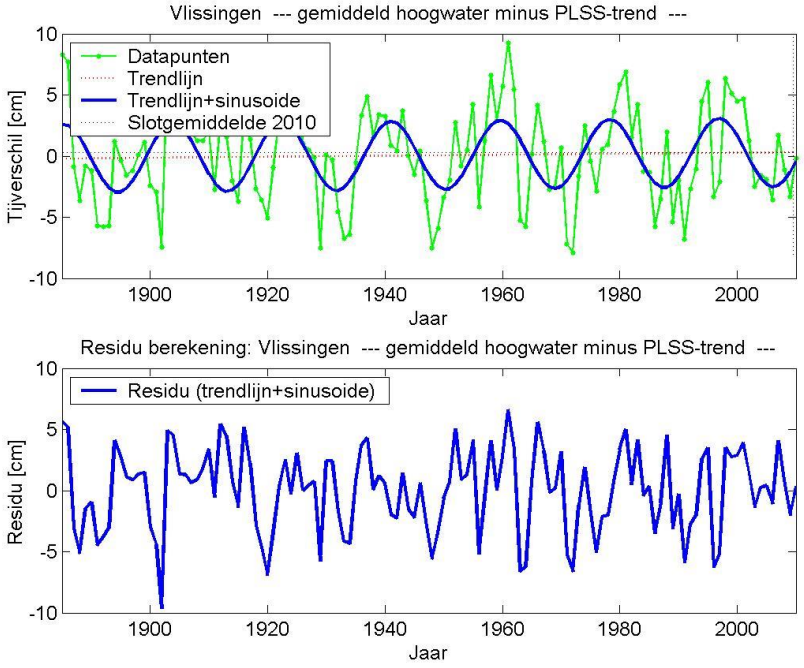


Knopencyclus Vlissingen

Gemiddelde zeespiegel

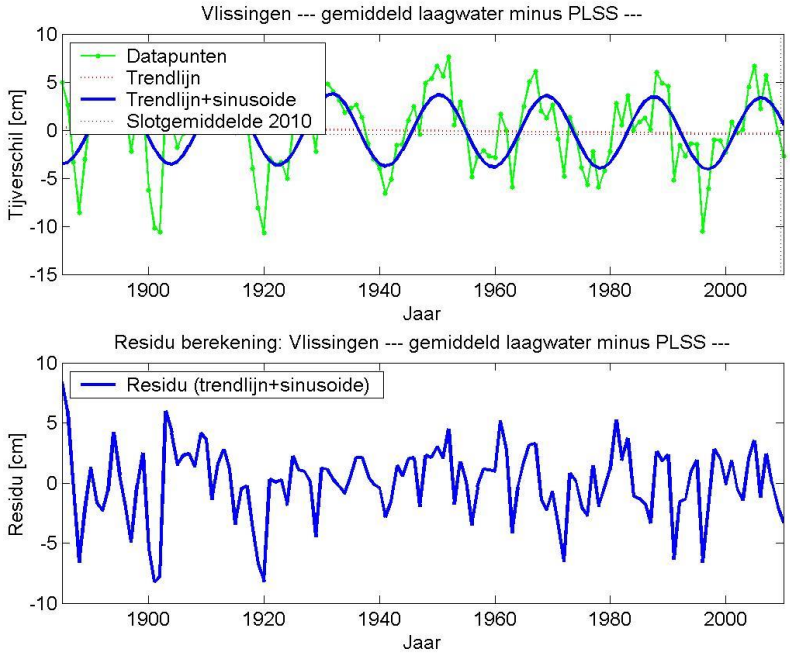


Gemiddeld hoogwater

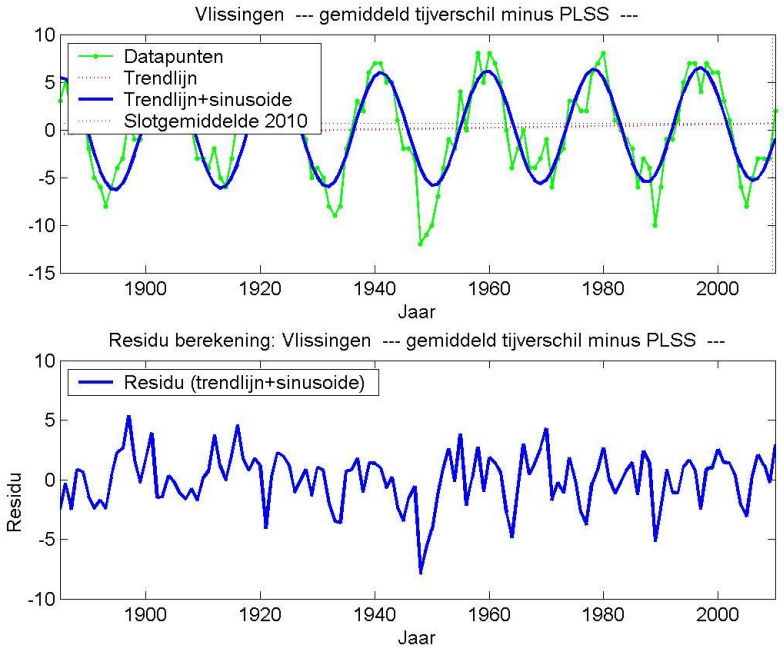


Knopencyclus Vlissingen

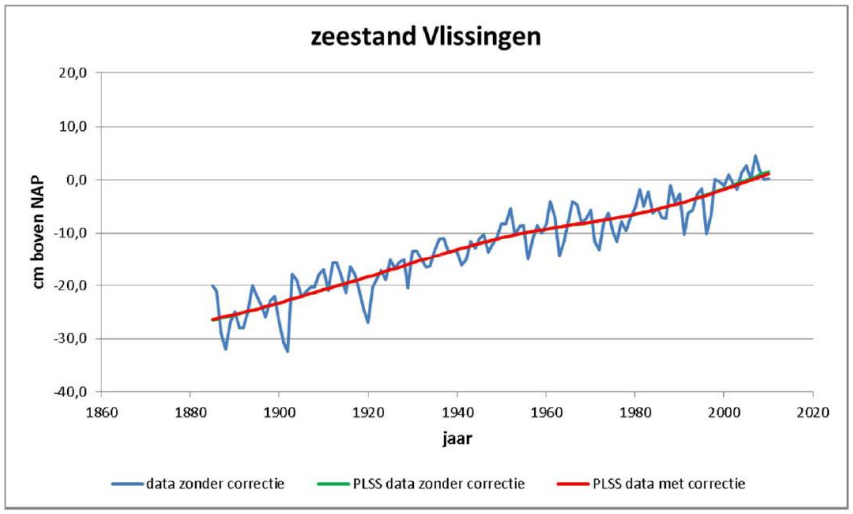
Gemiddeld laagwater

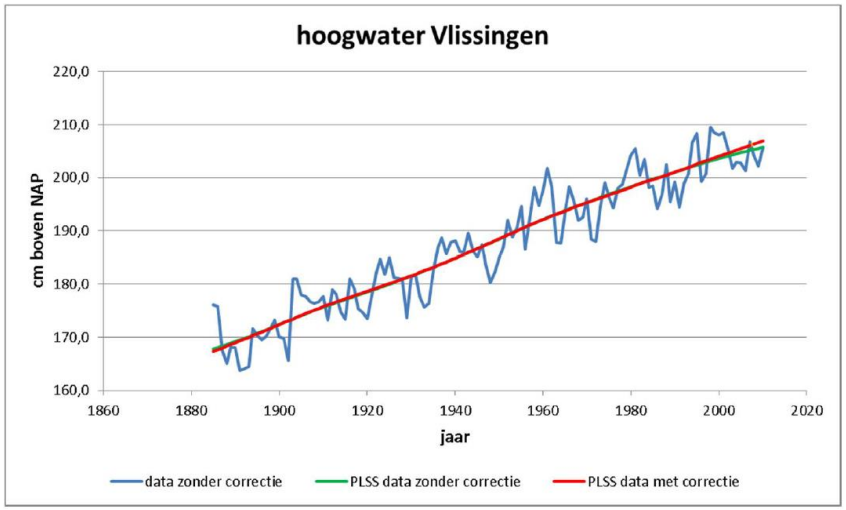


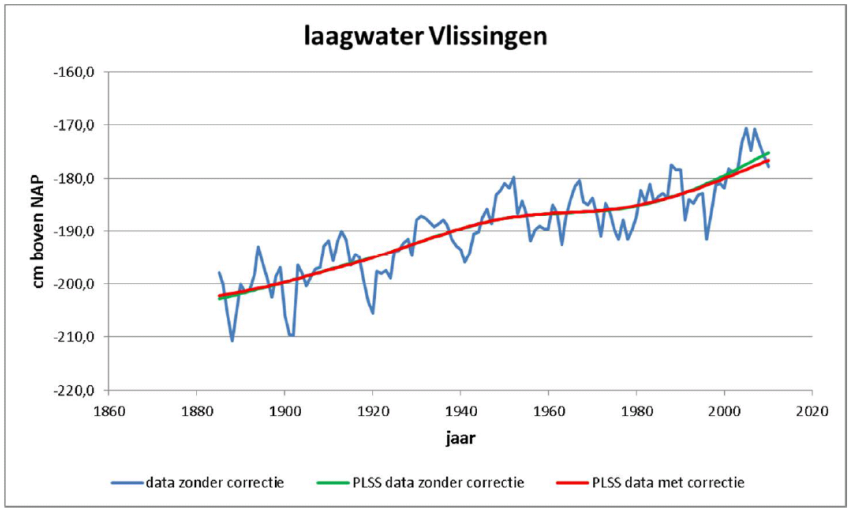
Gemiddeld tijverschil

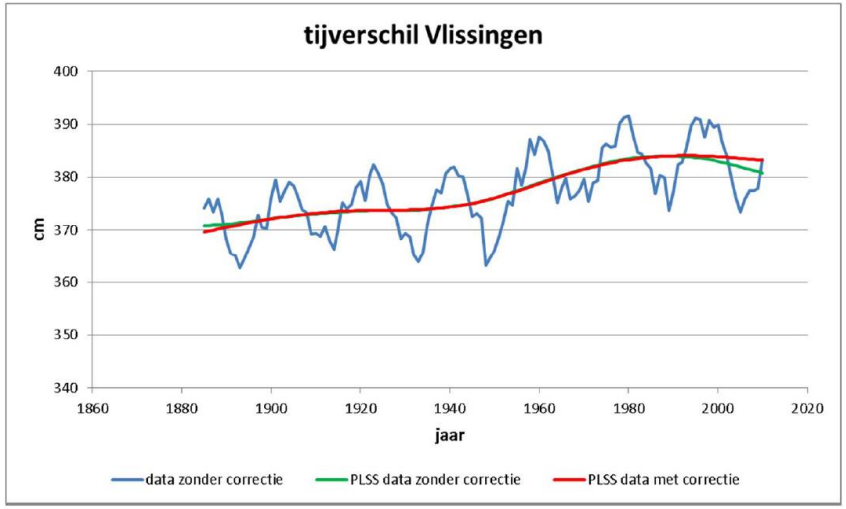


PLSS trend na correctie voor de knopencyclus



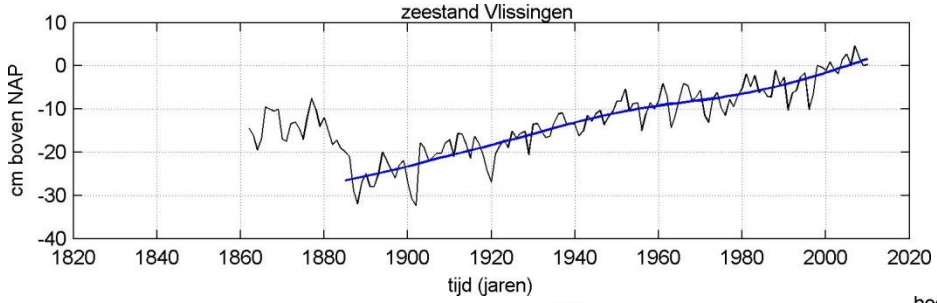


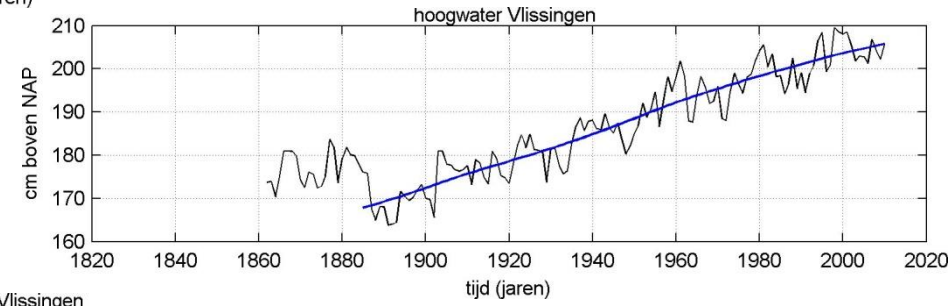


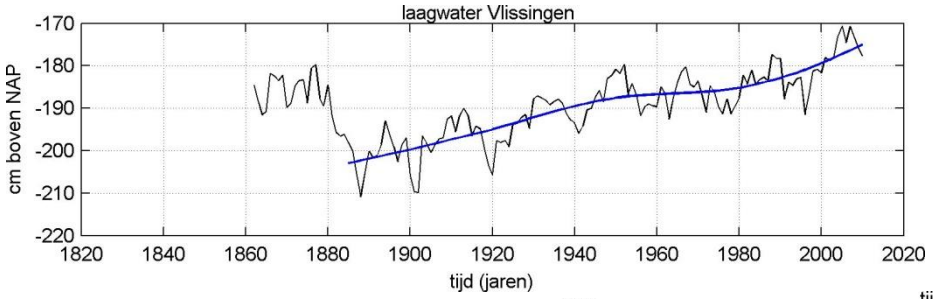


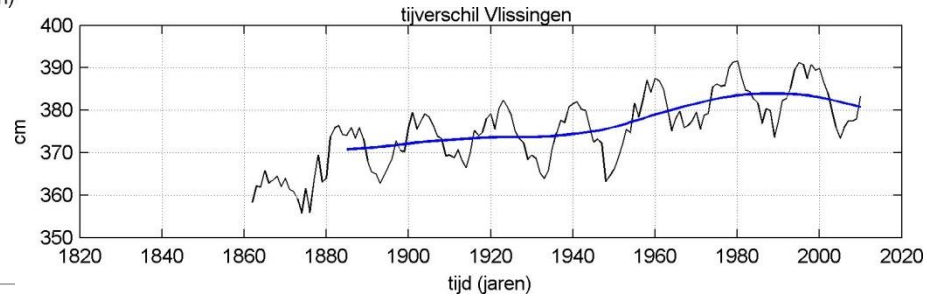
Deltares

Vlissingen

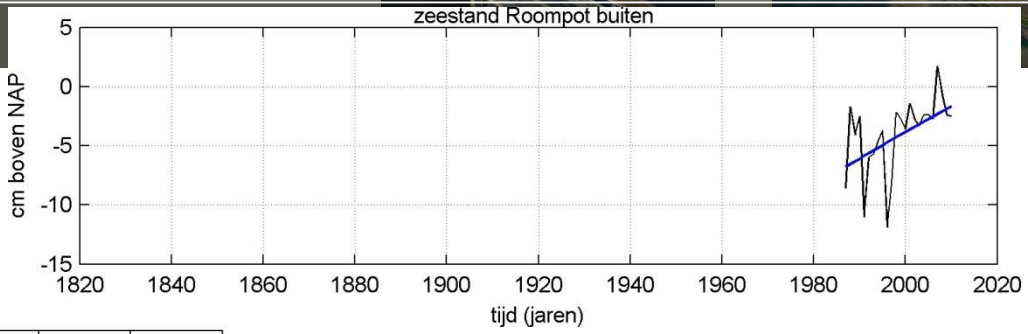

zeestand Vlissingen
cm boven NAP
10
0
-10
-20
-30
-40
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

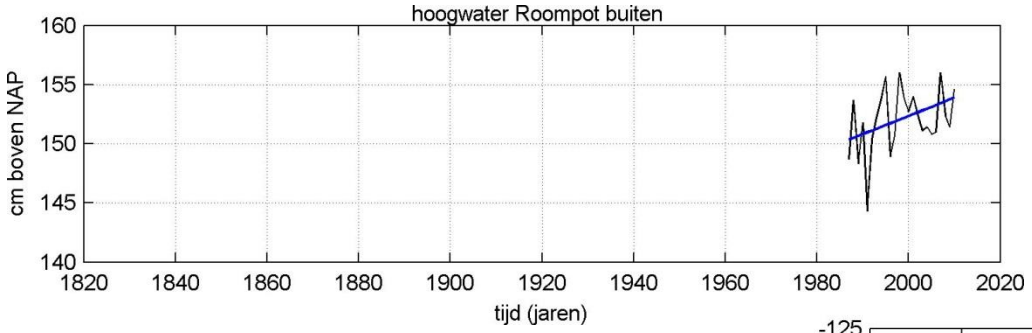

hoogwater Vlissingen
cm boven NAP
210
200
190
180
170
160
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

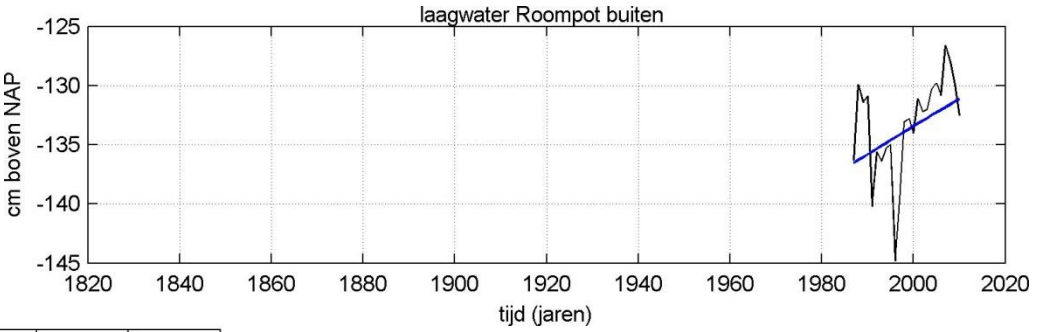

laagwater Vlissingen
cm boven NAP
-170
-180
-190
-200
-210
-220
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

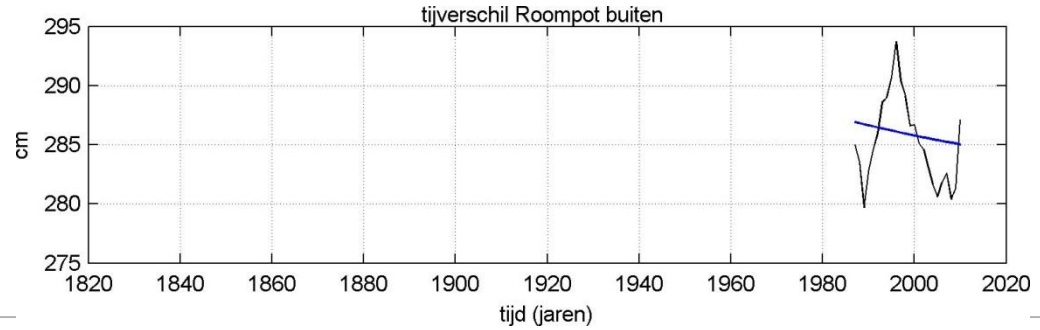

tijverschil Vlissingen
cm
400
390
380
370
360
350
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

Roompot buiten

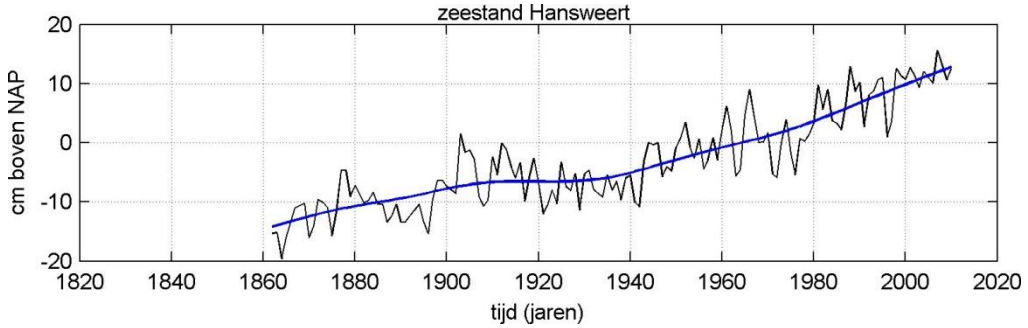


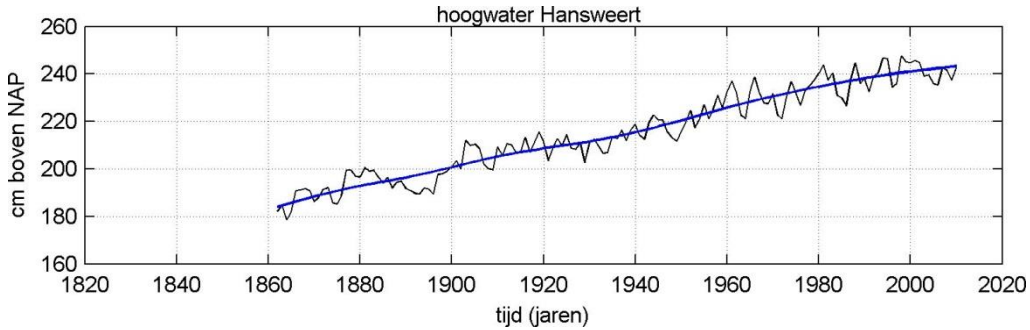


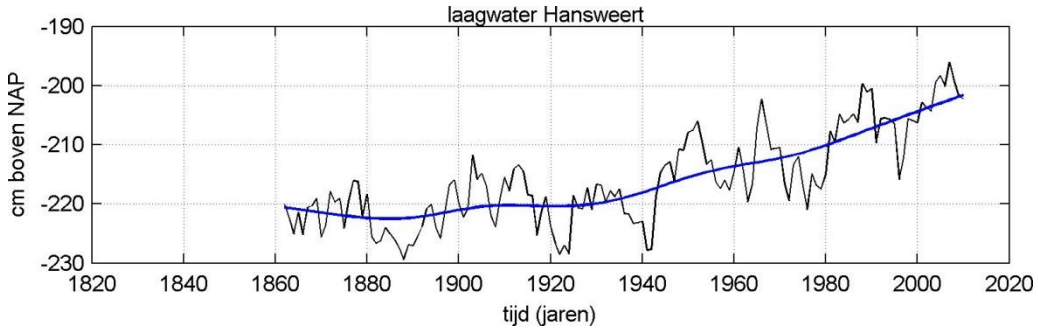




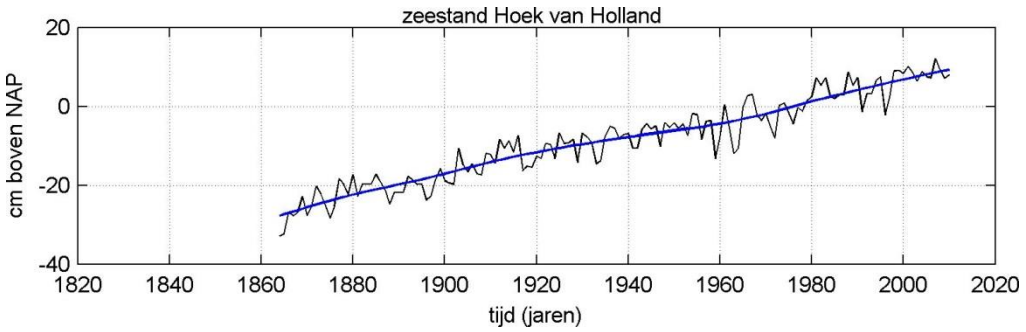
Hansweert

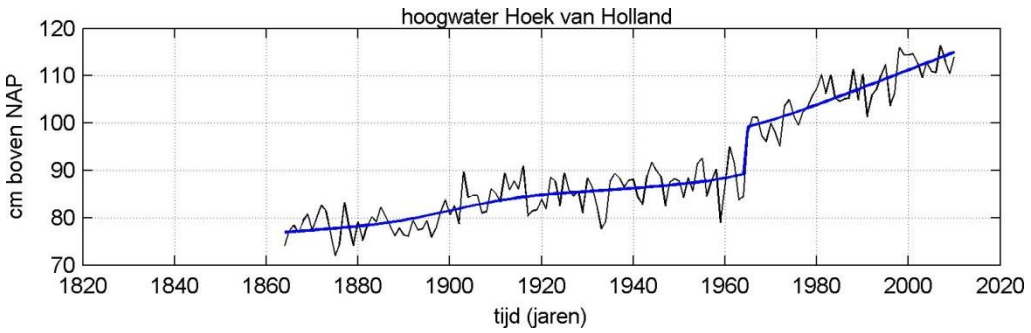

zeestand Hansweert
cm boven NAP
20
10
0
-10
-20
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

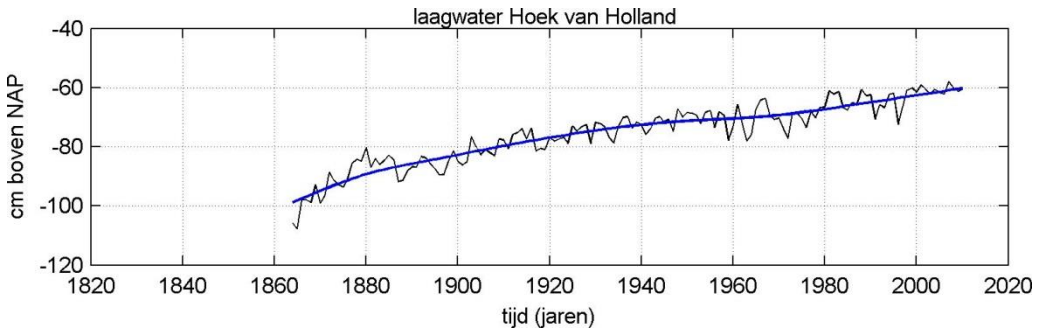

hoogwater Hansweert
cm boven NAP
260
240
220
200
180
160
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)


laagwater Hansweert
cm boven NAP
-190
-200
-210
-220
-230
1820
1840
1860
1880
1900
1920
1940
1960
1980
2000
2020
tijd (jaren)

Hoek van Holland

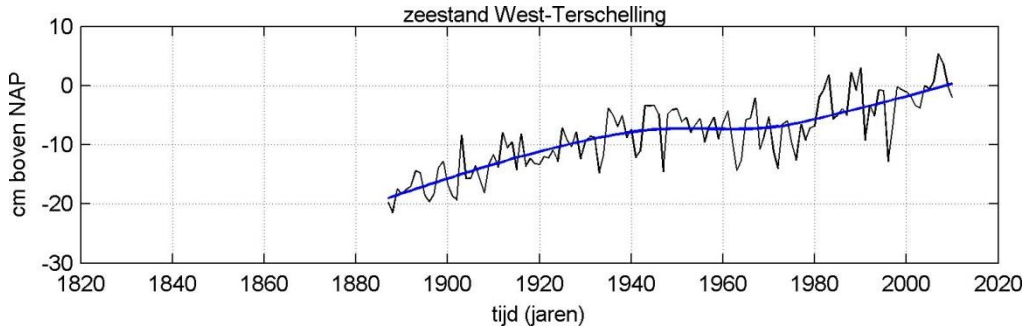


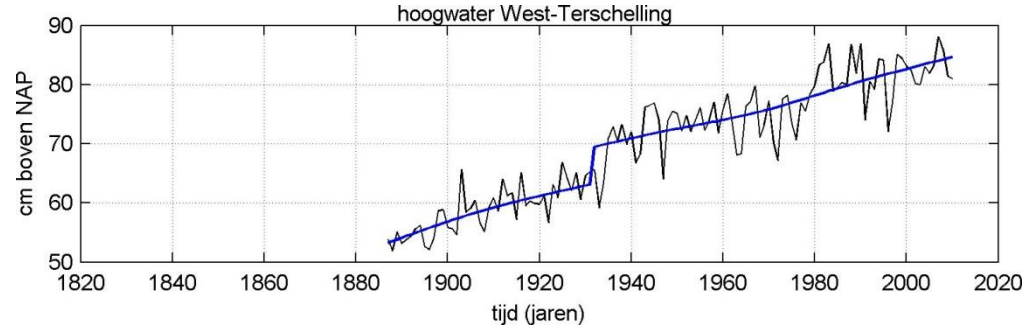


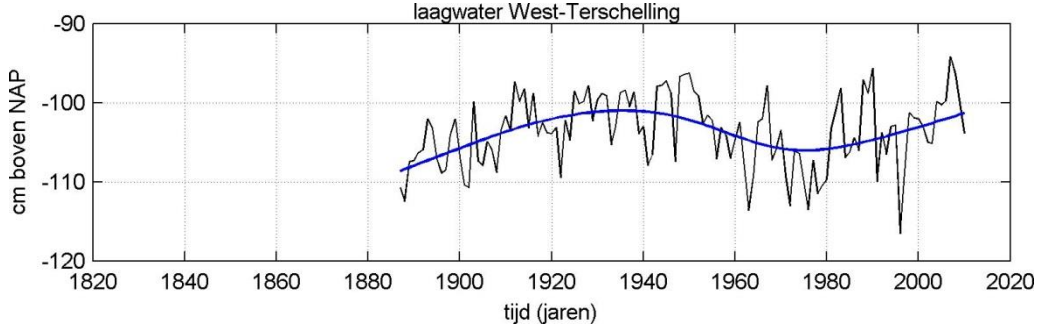


Deltares

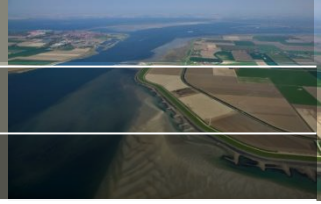
West-Terschelling







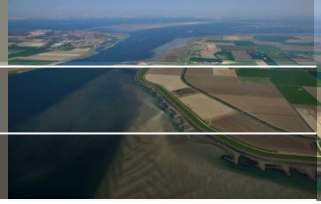
Gemiddelde stijgsnelheden [cm/eeuw]



	1900-2010					1933-2010					1971-2010				
Station	**HW**	**ZS**	**LW**	**HW-ZS**	**ZS-LW**	**HW**	**ZS**	**LW**	**HW-ZS**	**ZS-LW**	**HW**	**ZS**	**LW**	**HW-ZS**	**ZS-LW**
Bath	45	-	2	-	-	46	-	-5	-	-	46	18	-23	28	41
Hansweert	39	19	18	20	1	40	25	23	15	2	32	30	27	2	3
Terneuzen	37	24	18	13	6	37	23	19	14	4	30	22	17	8	5
Vlissingen	**31**	**22**	**21**	**9**	**1**	**32**	**21**	**19**	**11**	**2**	**29**	**23**	**24**	**6**	**-1**
Cadzand	20	-	-	-	-	16	-	-	-	-	8	15	16	-7	-1
Westkapelle	27	-	19	-	-	25	-	21	-	-	24	27	24	-3	3
Hoek van Holland	**22**	**24**	**20**	**-2**	**4**	**25**	**24**	**18**	**1**	**6**	**36**	**28**	**23**	**8**	**5**
Scheveningen	-	-	-	-	-	-	-	-	-	-	25	21	13	4	8
IJmuiden	**22**	**21**	**24**	**1**	**-3**	**25**	**21**	**27**	**4**	**-6**	**25**	**22**	**32**	**3**	**-10**
Den Helder	**22**	**15**	**10**	**7**	**5**	**21**	**16**	**11**	**5**	**5**	**23**	**18**	**14**	**5**	**4**
Oudeschild	20	-	16	-	-	19	-	14	-	-	19	22	8	-3	14
Vlieland haven	-	-	-	-	-	-	-	-	-	-	17	18	20	-1	-2
West-Terschelling	20	15	4	5	11	19	12	0	7	12	22	19	12	3	7
Nes	-	-	-	-	-	-	-	-	-	-	23	25	27	-2	-2
Schiermonnikoog	-	-	-	-	-	-	-	-	-	-	24	30	28	-6	2
Den Oever	26	-	28	-	-	24	-	32	-	-	28	35	41	-7	-6
Kornwerderzand	-	-	-	-	-	19	13	10	-	3	16	13	7	3	6
Harlingen	**25**	**13**	**10**	**12**	**3**	**23**	**13**	**4**	**10**	**9**	**18**	**15**	**-5**	**3**	**20**
Lauwersoog	-	-	-	-	-	-	-	-	-	-	27	27	14	0	13
Delfzijl	**22**	**19**	**8**	**3**	**11**	**22**	**19**	**2**	**3**	**17**	**24**	**21**	**3**	**3**	**18**
Nieuwe Statenzijl	21	-	-	-	-	21	-	-	-	-	19	-	-	-	-

Deltares

Conclusies



- Voor trendanalyses is het noodzakelijk de Nederlandse tijdreeksen voor gemiddelde zeeniveaus te corrigeren voor NAP-aanpassingen en voor de 18,6-jarige knopencyclus
- De beste schatting voor de gemiddelde relatieve zeespiegelstijging langs de Nederlandse kust is 19 cm/eeuw
- Een significante versnelling in de gemiddelde zeespiegel langs de Nederlandse kust valt nog niet te ontdekken
- Vrijwel alle tijdreeksen tonen beïnvloeding door uitgevoerde werken. Dat maakt het lastig om algemeen geldende conclusies te trekken uit de berekende stijgsnelheden voor verschillende periodes.
- De analyses geven aanleiding om het uitgangspunt dat langs de Hollandse en Waddenzeekust de stijging van het gemiddelde hoogwater gemiddeld globaal meer dan 5 cm/eeuw bedraagt dan die van de gemiddelde zeestand te heroverwegen

Deltares