North Sea coastal zone agriculture in times of sea level rise.

guest lecture at the Lincoln Institute for Agri-Food Technology
Lincoln University
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by Pier Vellinga

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Kennis voor Klimaat

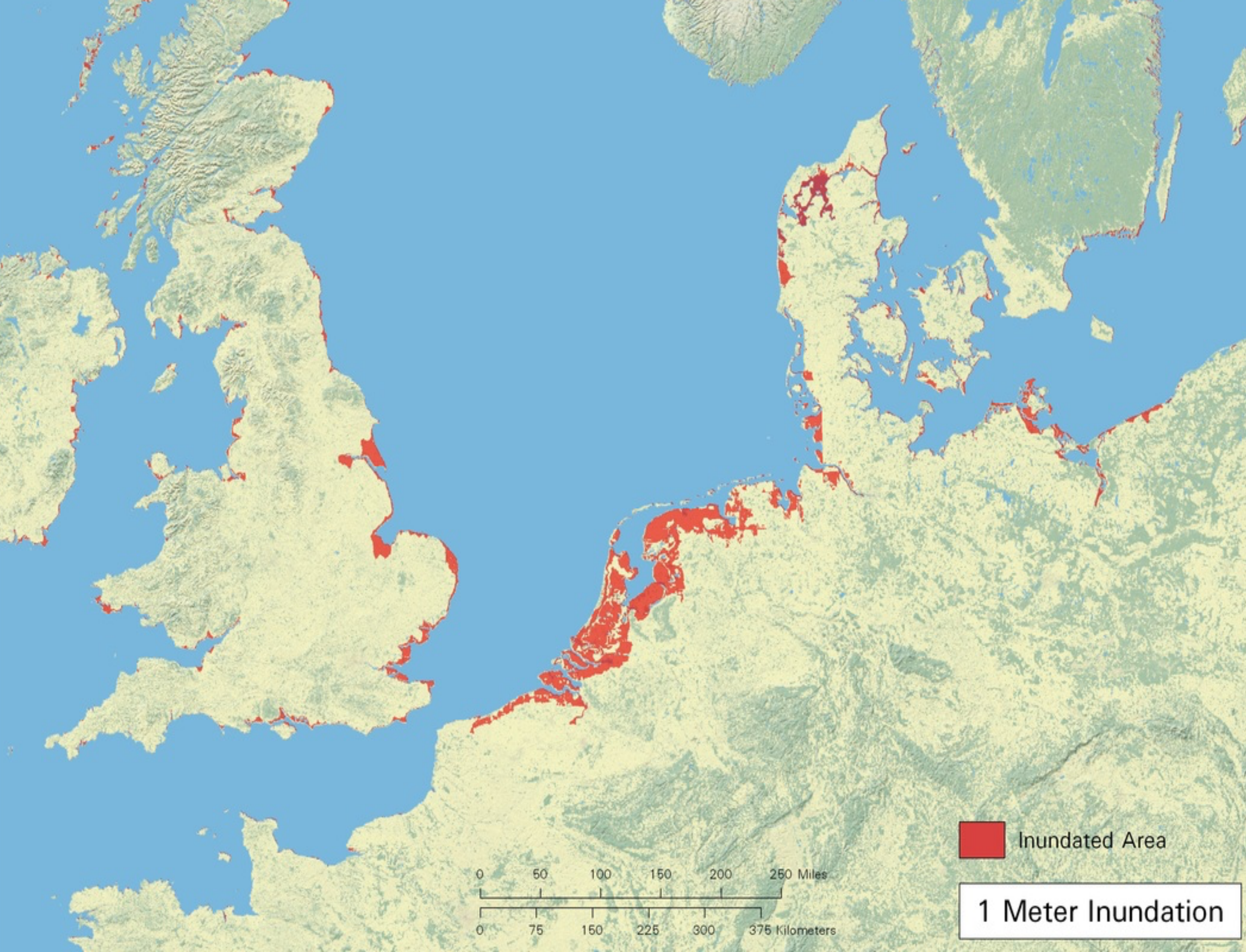
Waddenacademie

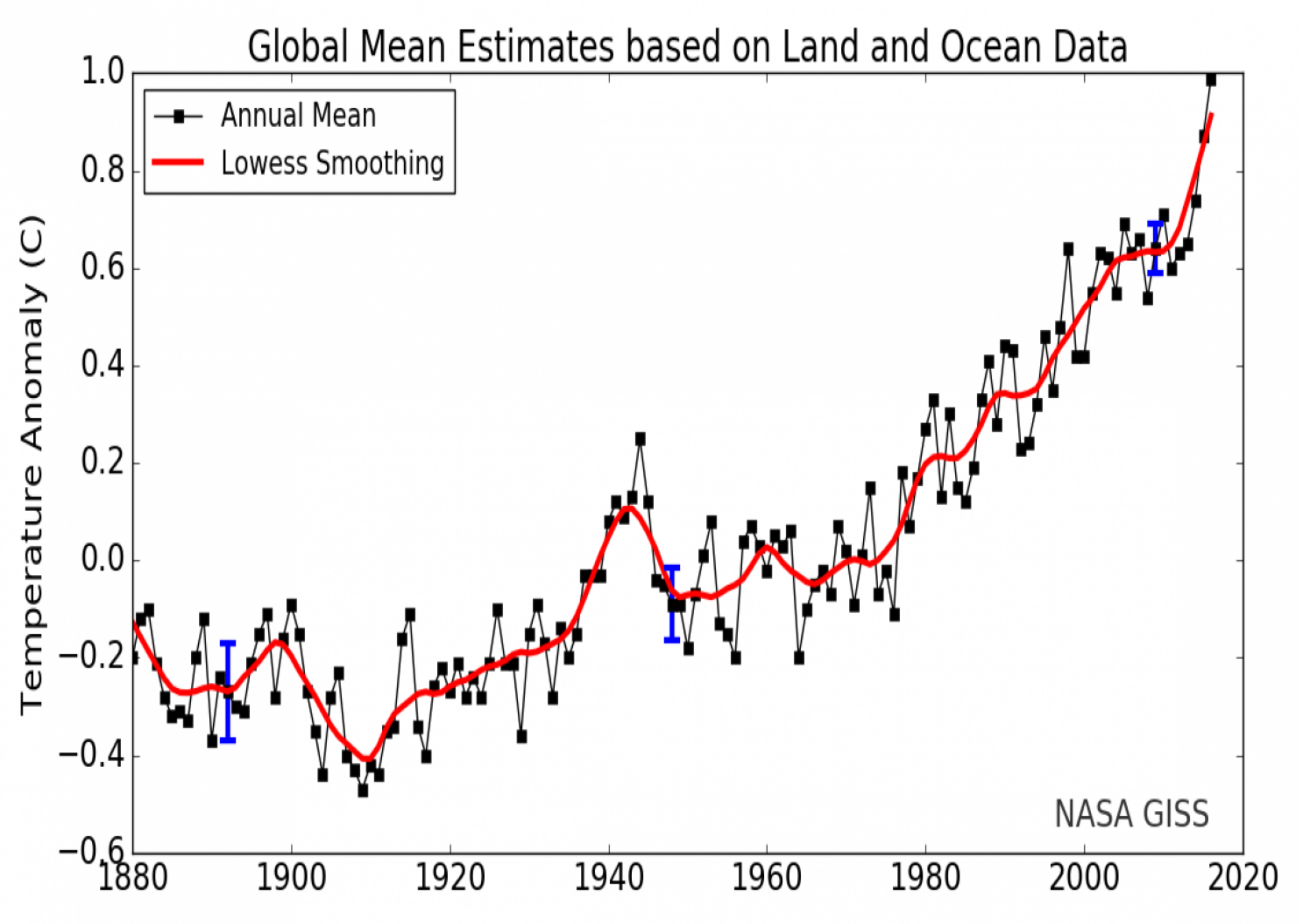
Lecture in four parts

- North Sea; sea level rise projections for 2100;
- Coastal zone policy in the Netherlands;
- Trying to keep salinity out
- Exploring saline farming options;

Sea level rise projections

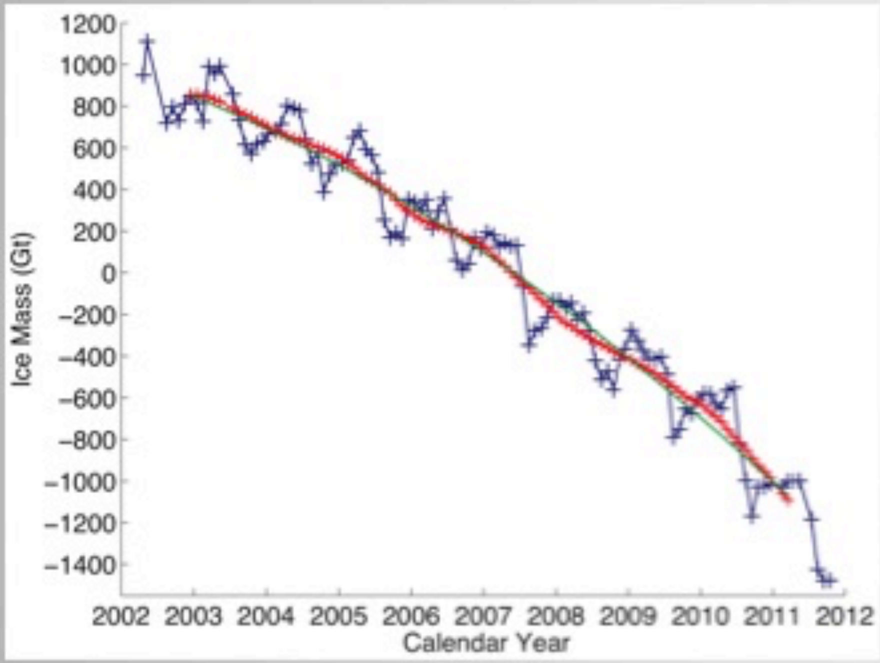
- Global average sea level rise projections;
- Regional aspects;


Inundated Area
0 50 100 150 200 250 Miles
0 75 150 225 300 375 Kilometers
1 Meter Inundation

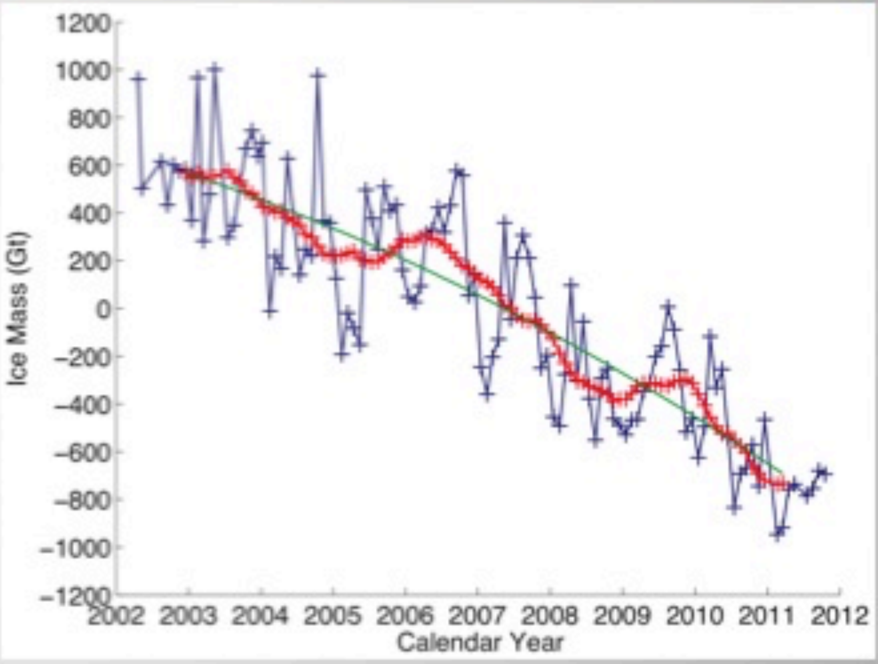

Global Mean Estimates based on Land and Ocean Data
Annual Mean
Lowess Smoothing
Temperature Anomaly (C)
1.0
0.8
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
1880
1900
1920
1940
1960
1980
2000
2020
NASA GISS

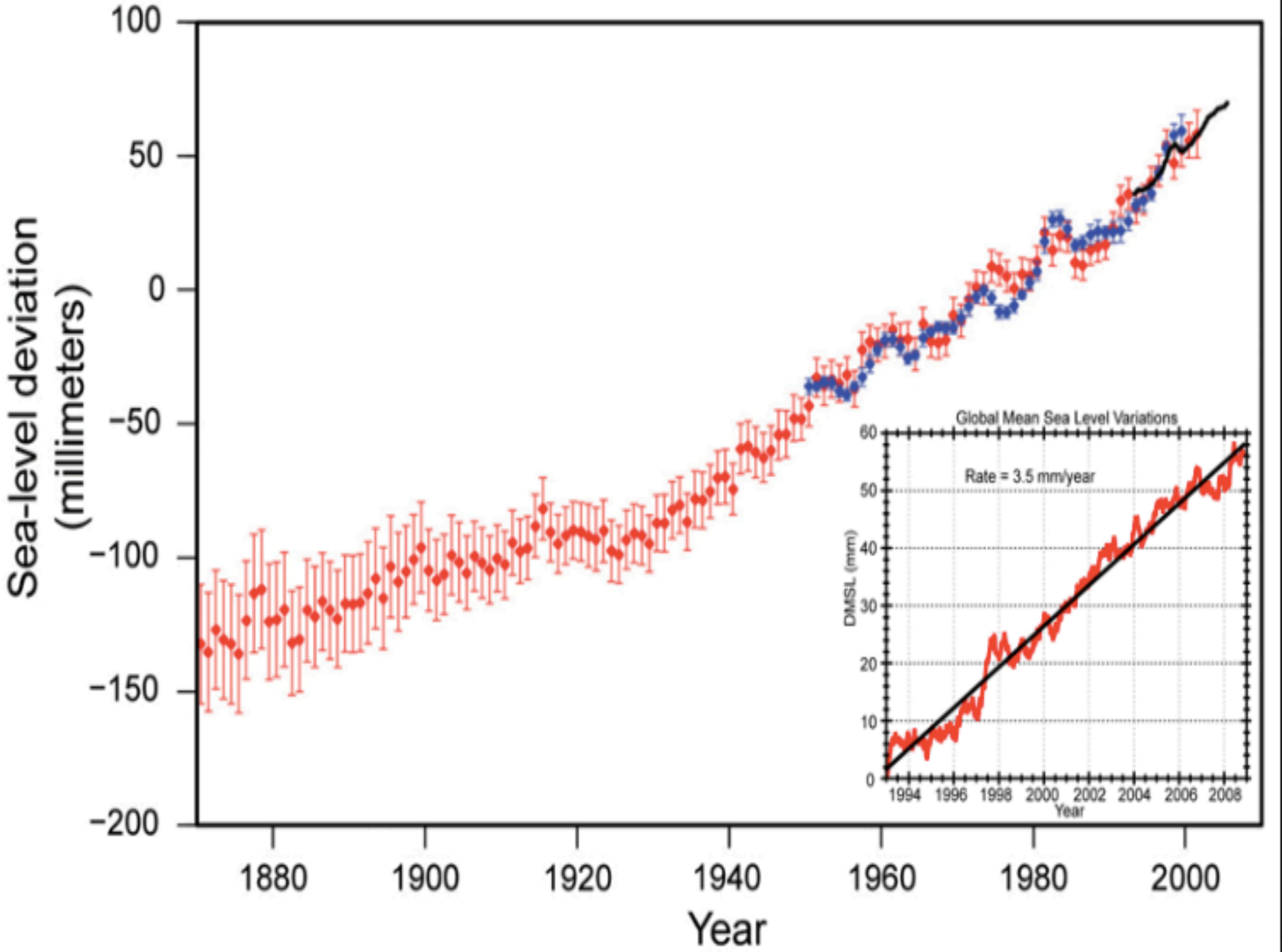
ICE MASS LOSS FROM GRACE

Greenland

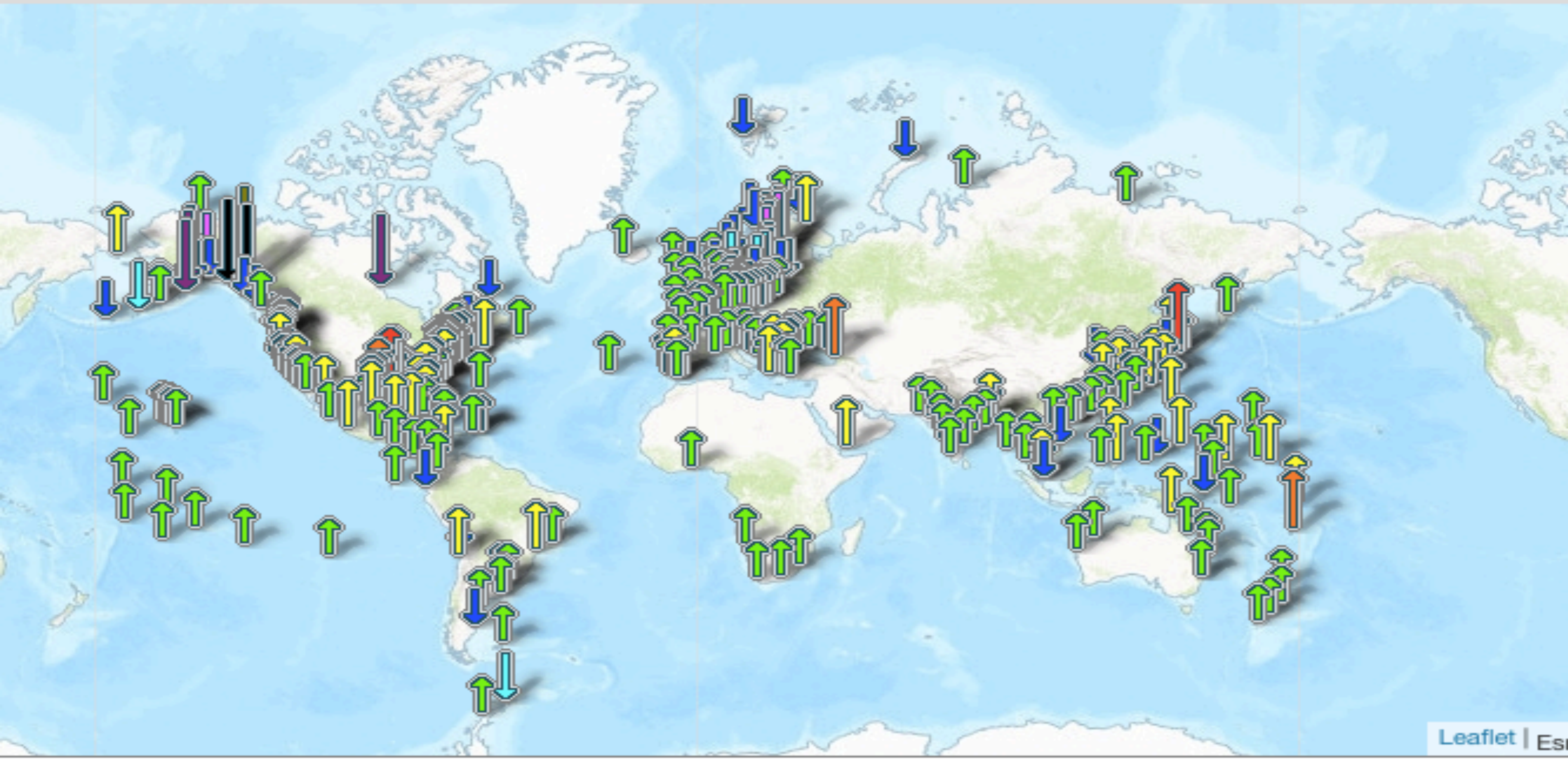


Antarctica

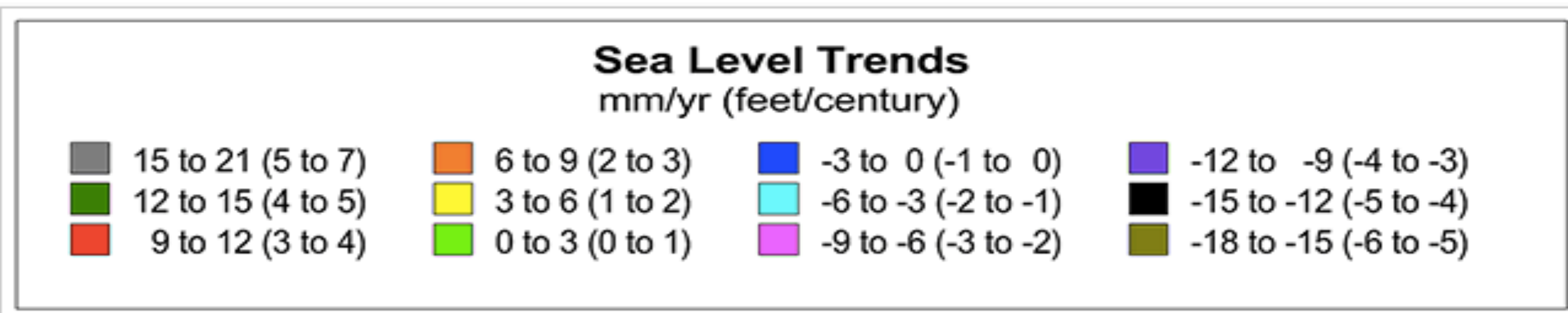




Sea-level deviation (millimeters)
100
50
0
−50
−100
−150
−200
1880
1900
1920
1940
1960
1980
2000
Year
Global Mean Sea Level Variations
Rate = 3.5 mm/year
DMSL (mm)
60
50
40
30
20
10
0
1994
1996
1998
2000
2002
2004
2006
2008
Year



llustrates regional trends in sea level, with arrows representing the direction and magnitude of change. Click on an ar
information about that station.



Sources / contributions to global mean sea level rise in mm/year

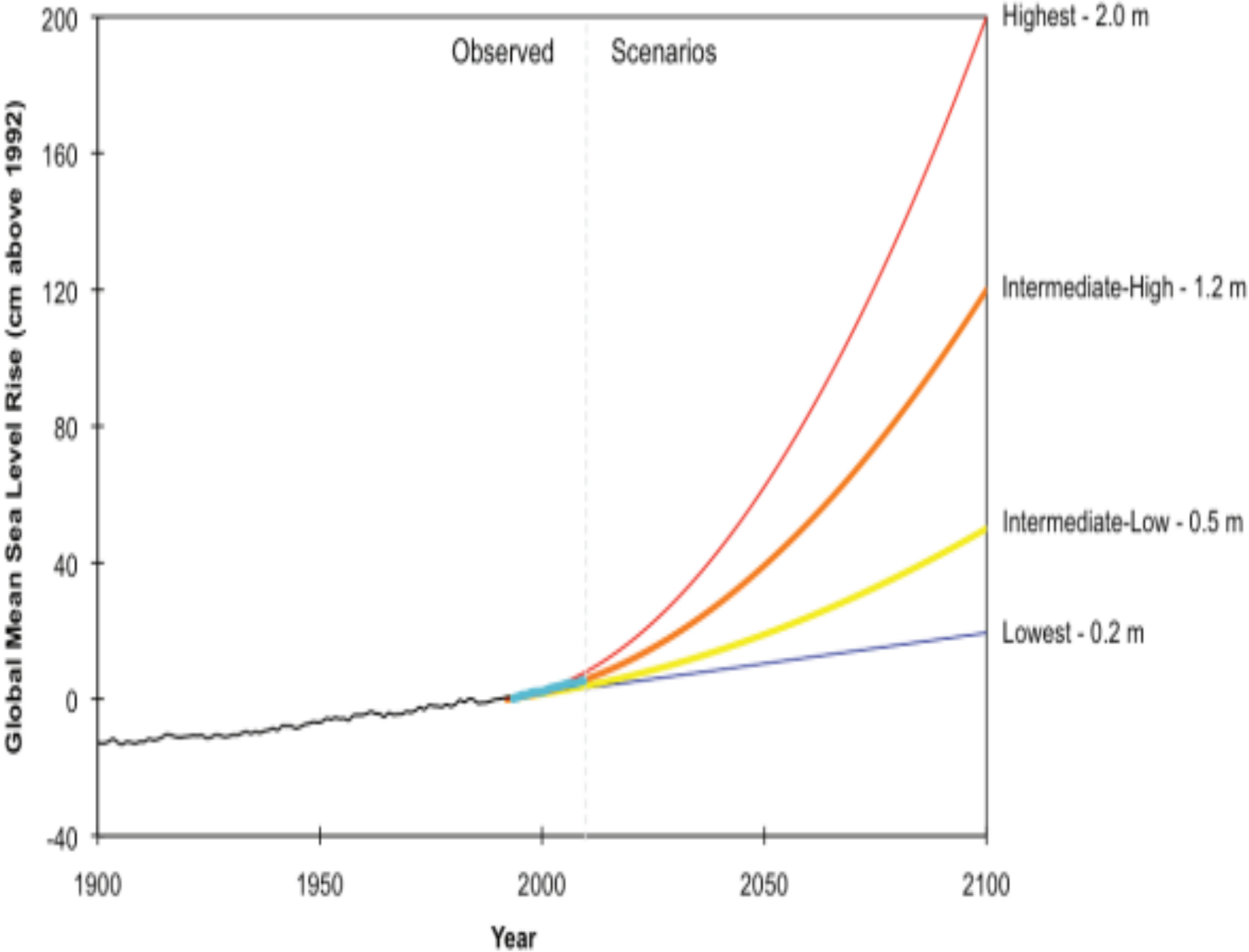
Source	1901–1990	1971–2010	1993–2010
Observed contributions to global mean sea level (GMSL) rise			
Thermal expansion	–	0.8 [0.5 to 1.1]	1.1 [0.8 to 1.4]
Glaciers except in Greenland and Antarctica[a]	0.54 [0.47 to 0.61]	0.62 [0.25 to 0.99]	0.76 [0.39 to 1.13]
Glaciers in Greenland[a]	0.15 [0.10 to 0.19]	0.06 [0.03 to 0.09]	0.10 [0.07 to 0.13][b]
Greenland ice sheet	–	–	0.33 [0.25 to 0.41]
Antarctic ice sheet	–	–	0.27 [0.16 to 0.38]
Land water storage	−0.11 [−0.16 to −0.06]	0.12 [0.03 to 0.22]	0.38 [0.26 to 0.49]
Total of contributions	**–**	**–**	**2.8 [2.3 to 3.4]**
Observed GMSL rise	**1.5 [1.3 to 1.7]**	**2.0 [1.7 to 2.3]**	**3.2 [2.8 to 3.6]**
Modelled contributions to GMSL rise			
Thermal expansion	0.37 [0.06 to 0.67]	0.96 [0.51 to 1.41]	1.49 [0.97 to 2.02]
Glaciers except in Greenland and Antarctica	0.63 [0.37 to 0.89]	0.62 [0.41 to 0.84]	0.78 [0.43 to 1.13]
Glaciers in Greenland	0.07 [−0.02 to 0.16]	0.10 [0.05 to 0.15]	0.14 [0.06 to 0.23]
Total including land water storage	**1.0 [0.5 to 1.4]**	**1.8 [1.3 to 2.3]**	**2.8 [2.1 to 3.5]**
Residual[c]	**0.5 [0.1 to 1.0]**	**0.2 [−0.4 to 0.8]**	**0.4 [−0.4 to 1.2]**

Notes:

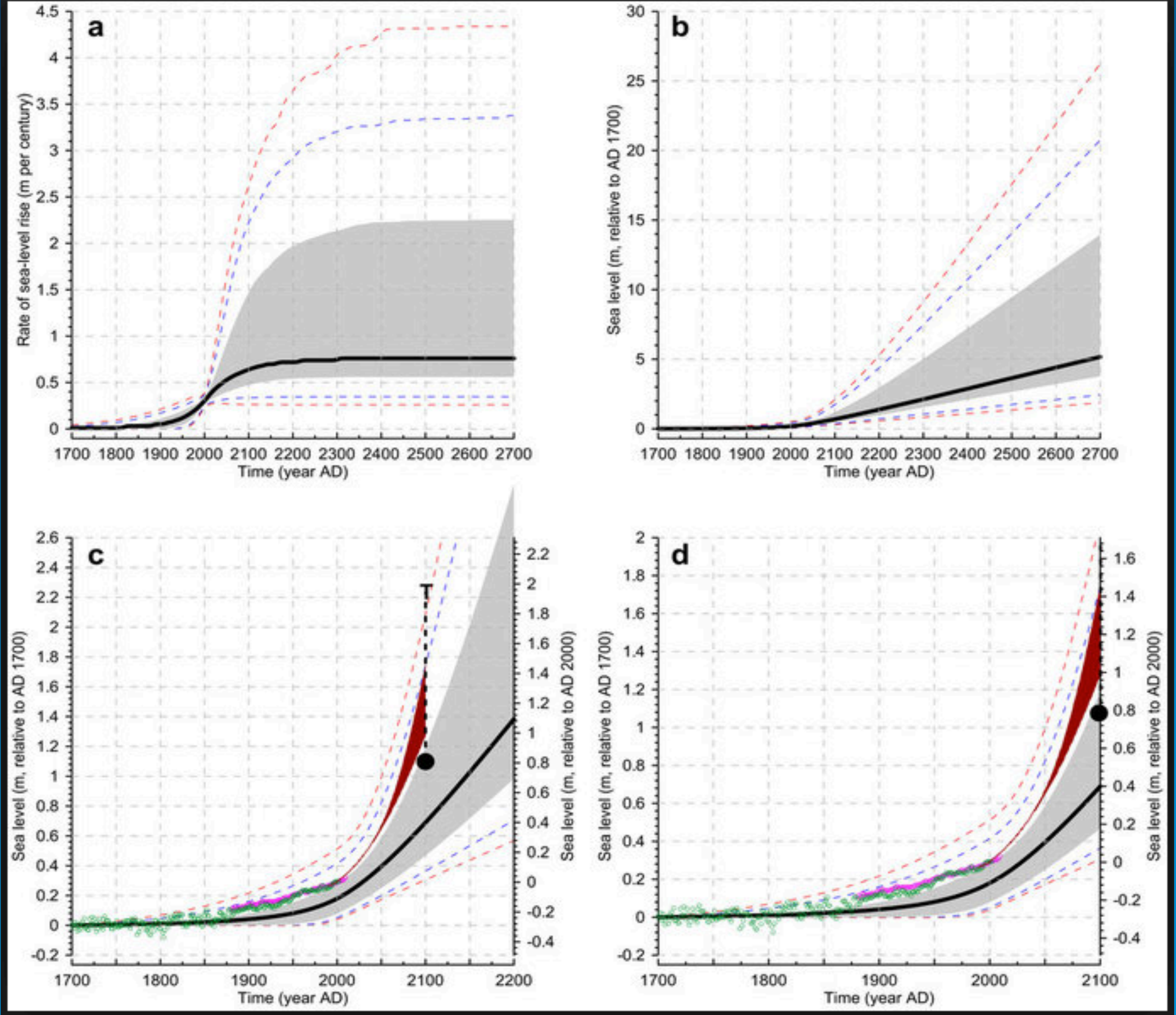
[a] Data for all glaciers extend to 2009, not 2010.

[b] This contribution is not included in the total because glaciers in Greenland are included in the observational assessment of the Greenland ice sheet.

[c] Observed GMSL rise – modelled thermal expansion – modelled glaciers – observed land water storage.



Observed
Scenarios
Highest - 2.0 m
Intermediate-High - 1.2 m
Intermediate-Low - 0.5 m
Lowest - 0.2 m
Global Mean Sea Level Rise (cm above 1992)
200
160
120
80
40
0
-40
1900
1950
2000
2050
2100
Year

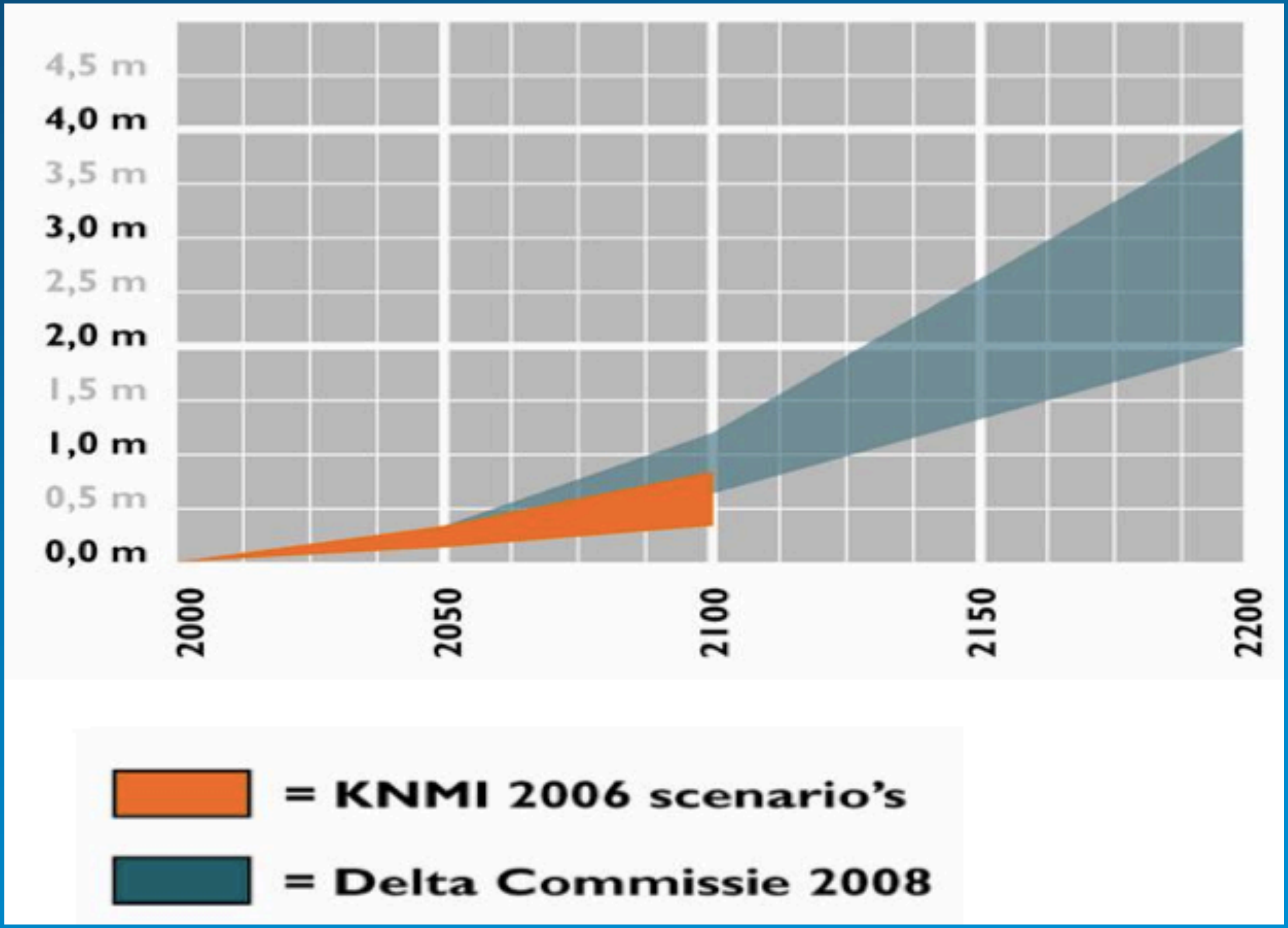


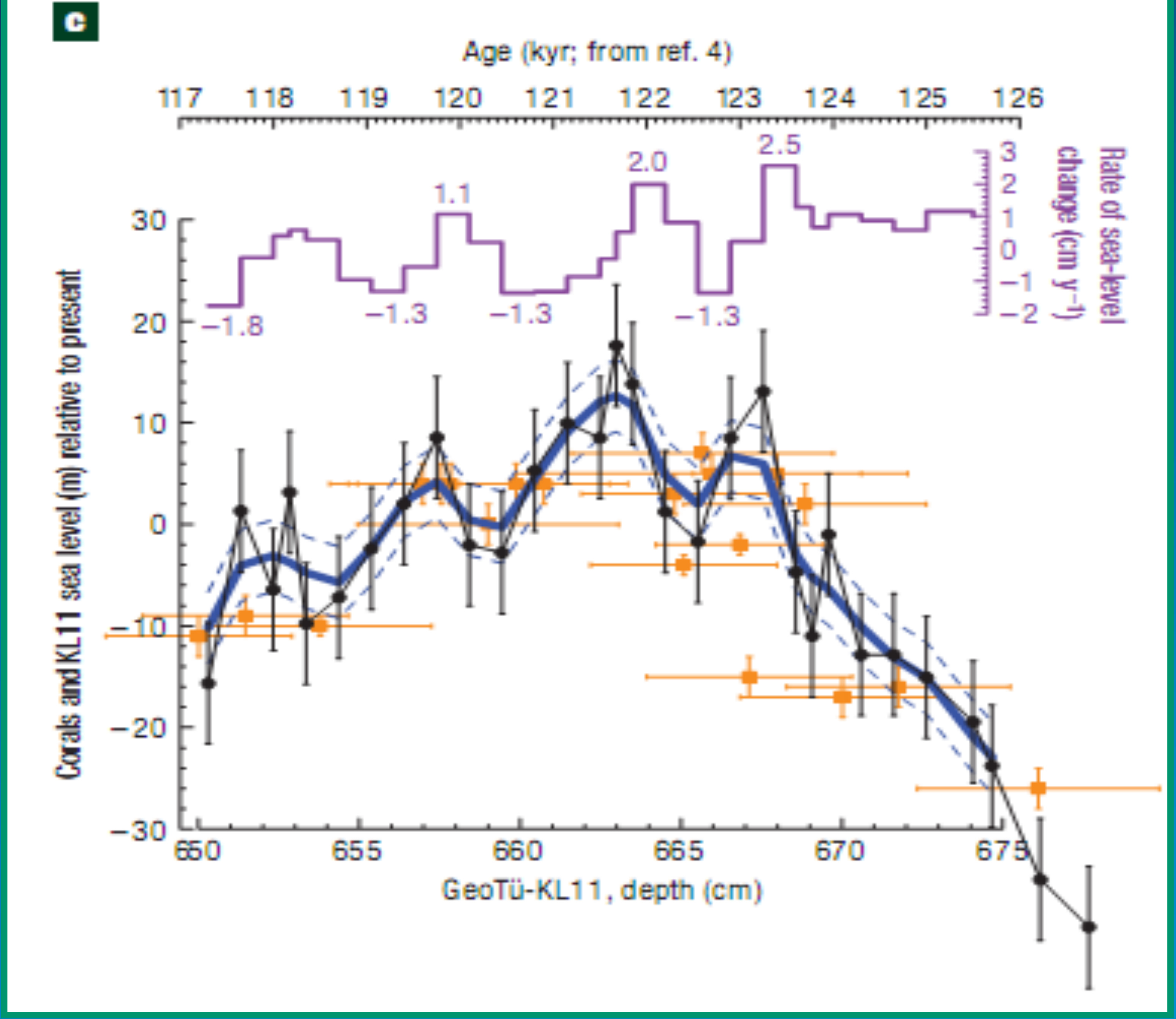
a
Rate of sea-level rise (m per century)
Time (year AD)
b
Sea level (m, relative to AD 1700)
Time (year AD)
c
Sea level (m, relative to AD 1700)
Sea level (m, relative to AD 2000)
Time (year AD)
d
Sea level (m, relative to AD 1700)
Sea level (m, relative to AD 2000)
Time (year AD)

Sea level rise North Sea

- Thermal expansion;
- Ice and snow melt on land;
- Antarctic ice melt times 1.2 -1.4 (due to mainly gravitional effects);
- Greenland ice melt times 0.3 – 0.4 (due to mainly gravitational effects);

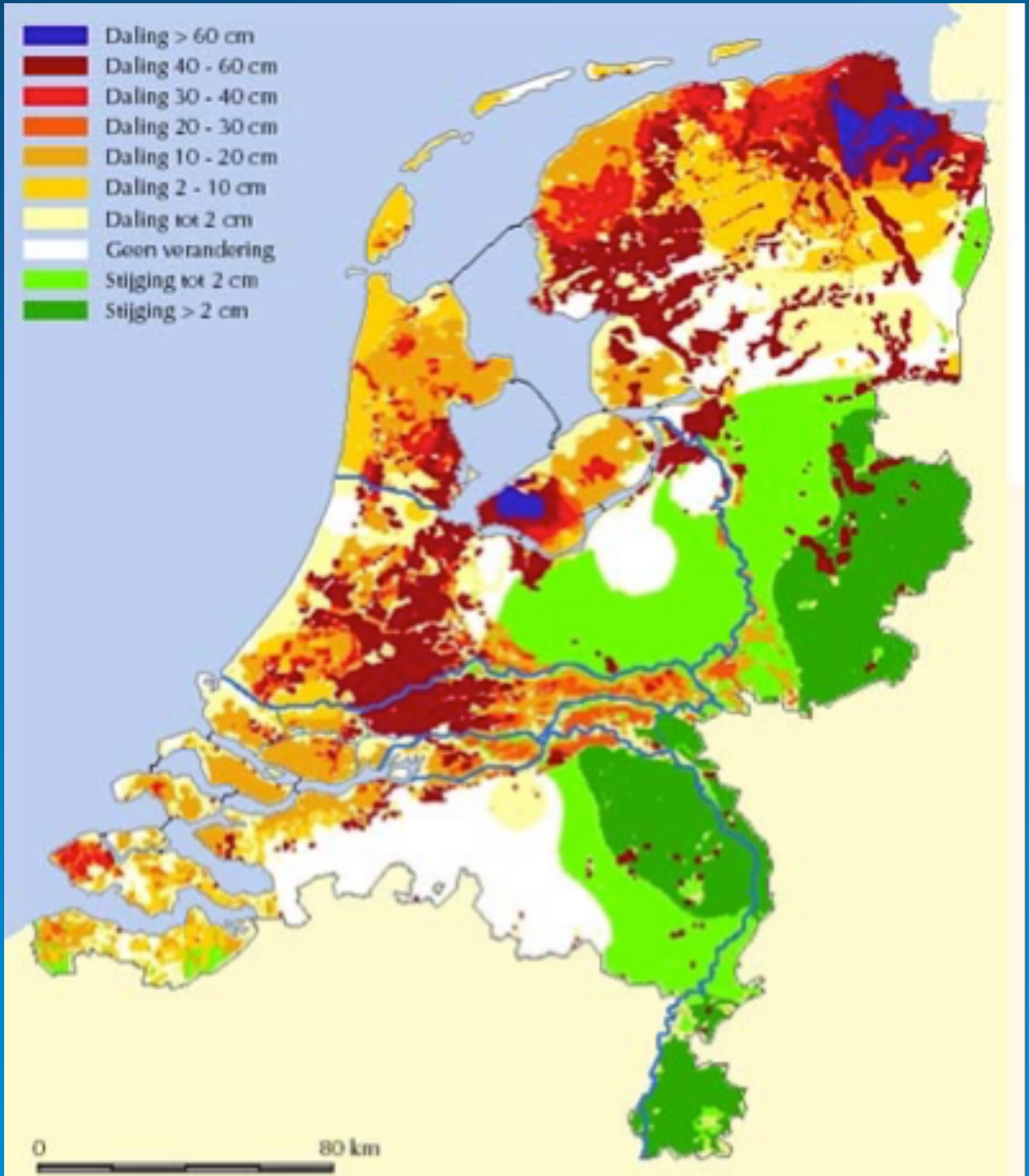
best guess and upper end sea level rise projections in m The Netherlands, KNMI and Delta Committee.





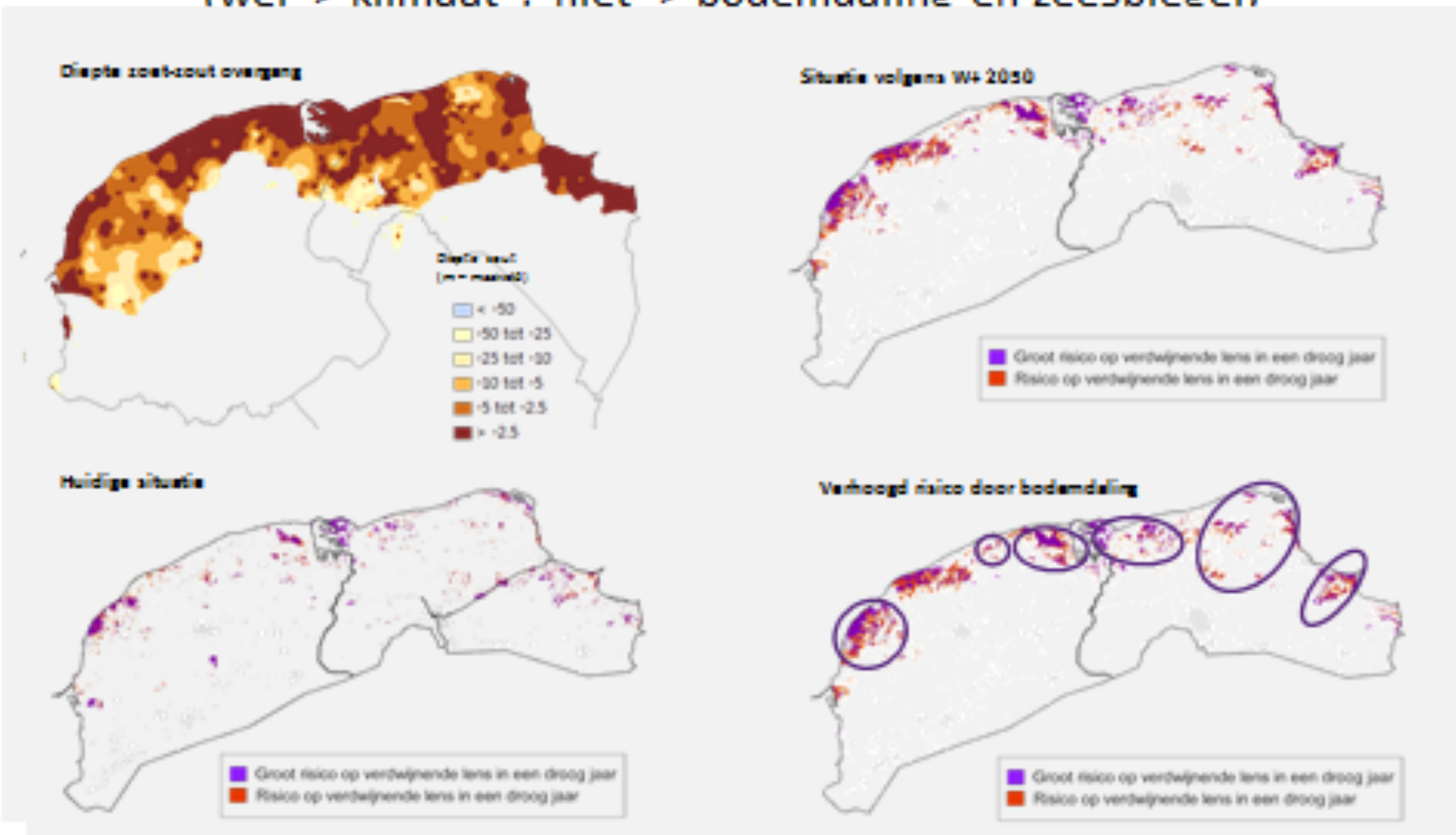
Bron: Rohling et al (2007)

Subsidence 2050



Friesland en Groningen

(wel -> klimaat : niet -> bodemdaling en zeespiegel)



water

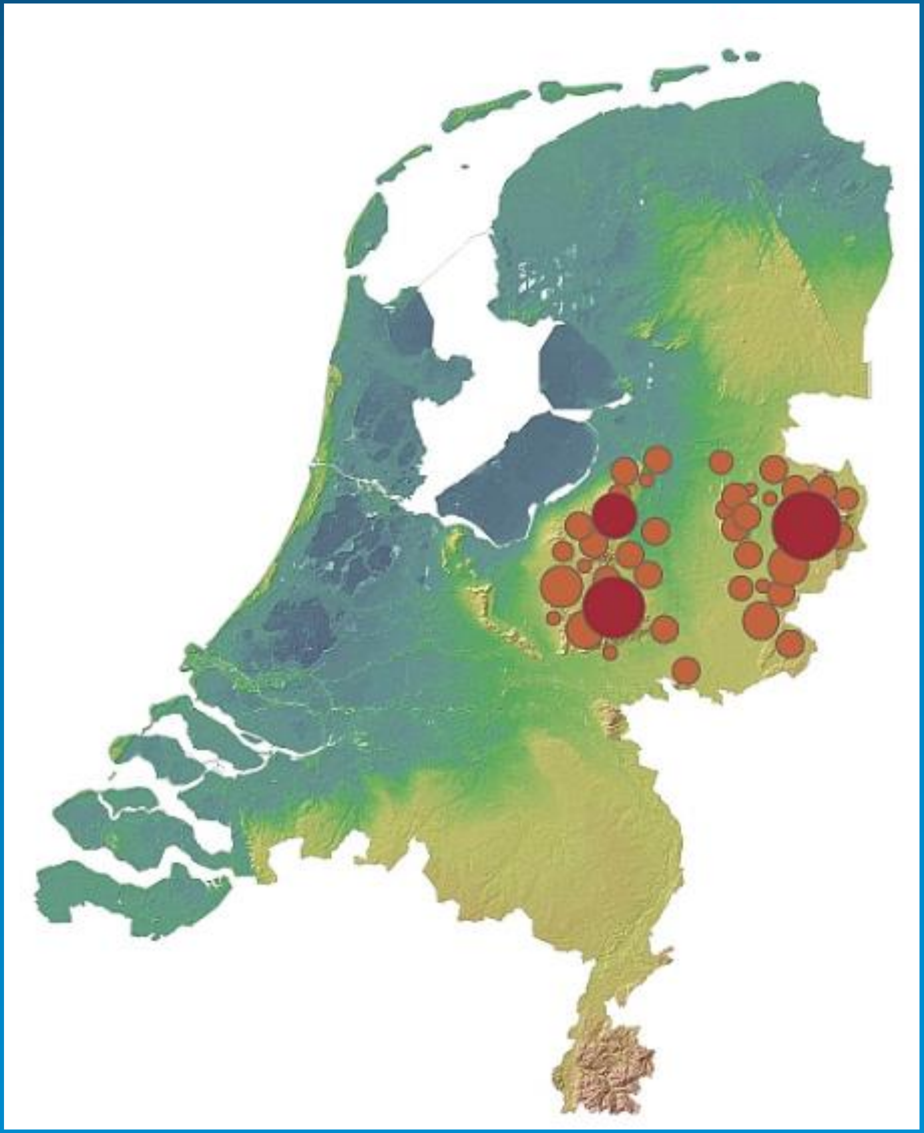
Three options for climate proofing the Netherlands in view of sea level rise.

1. Selective retreat towards higher grounds.

2. An offensive strategy by moving seaward;

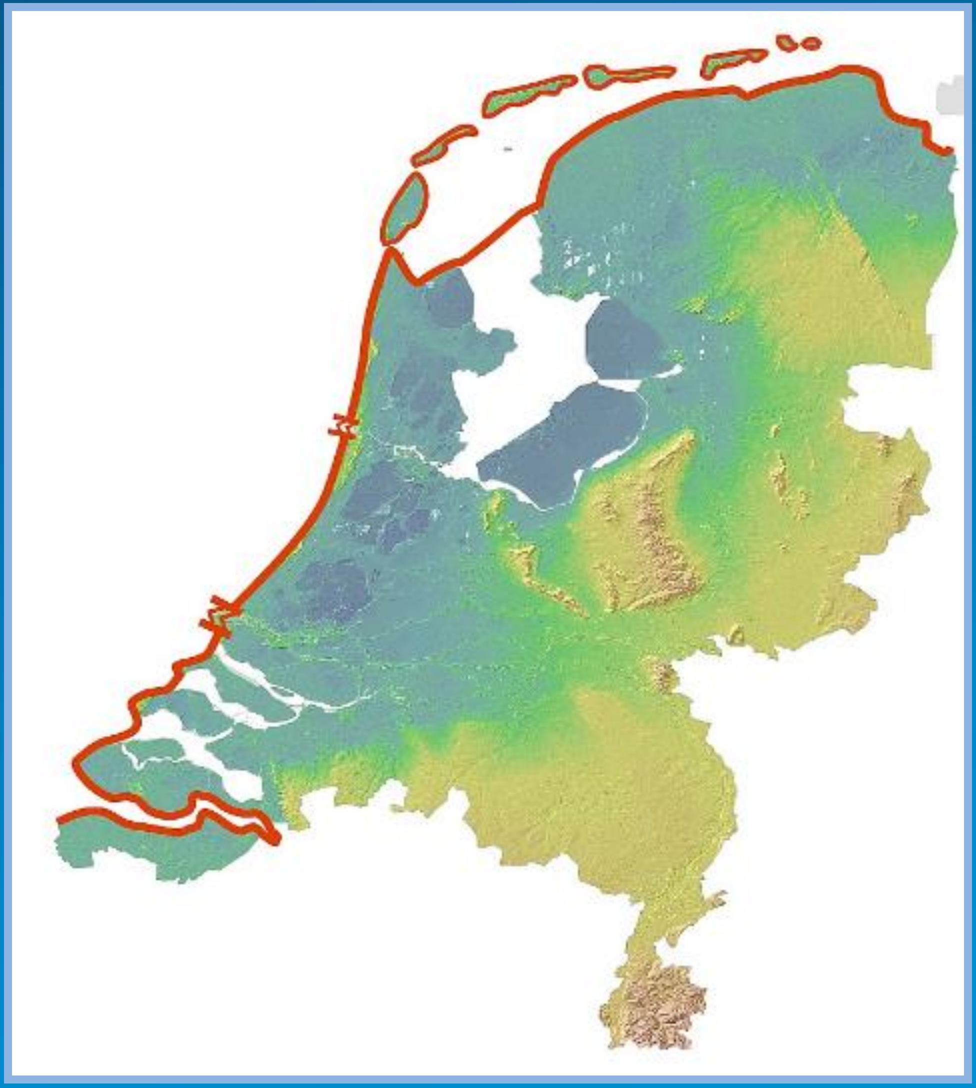
3. Protection within existing contours with two different options

Option 1 retreat to higher grounds

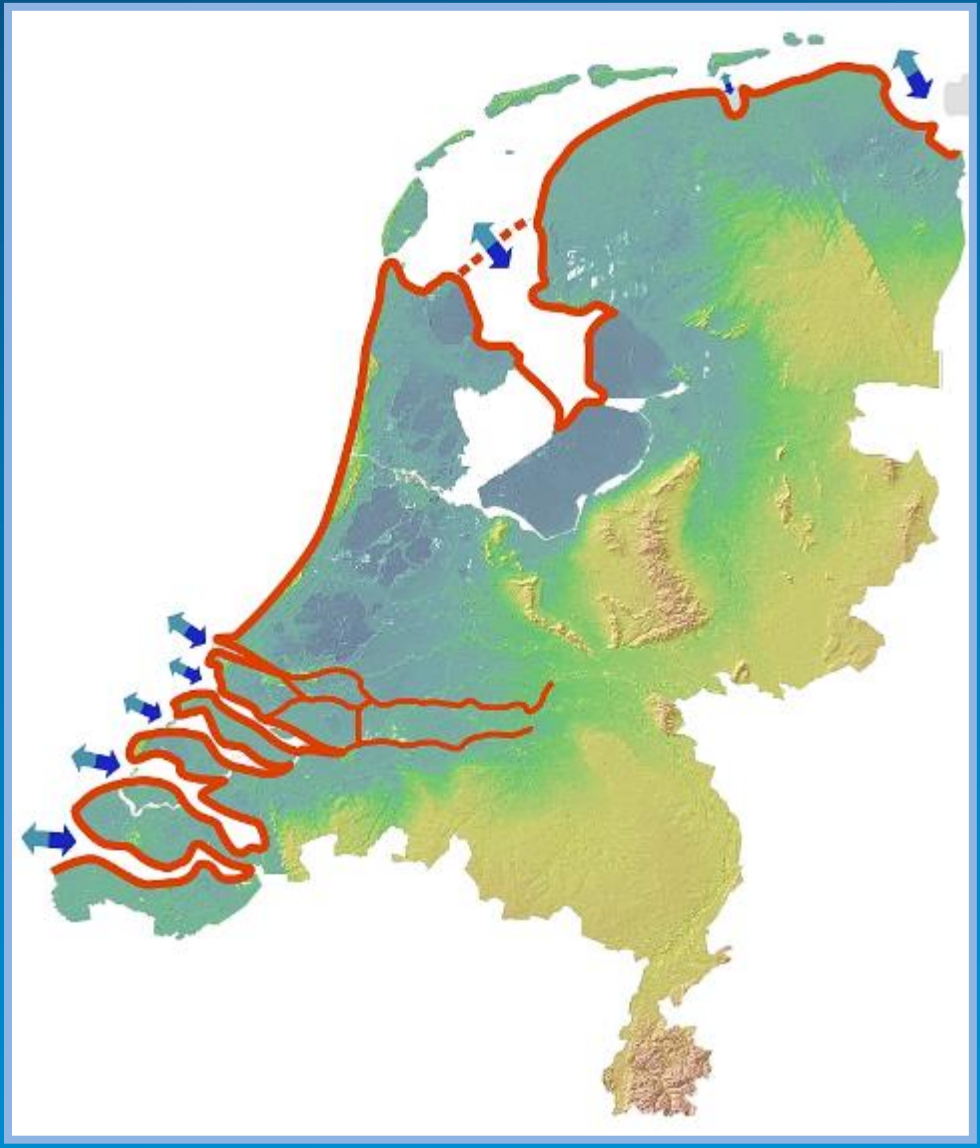


Option 2: offensive strategy

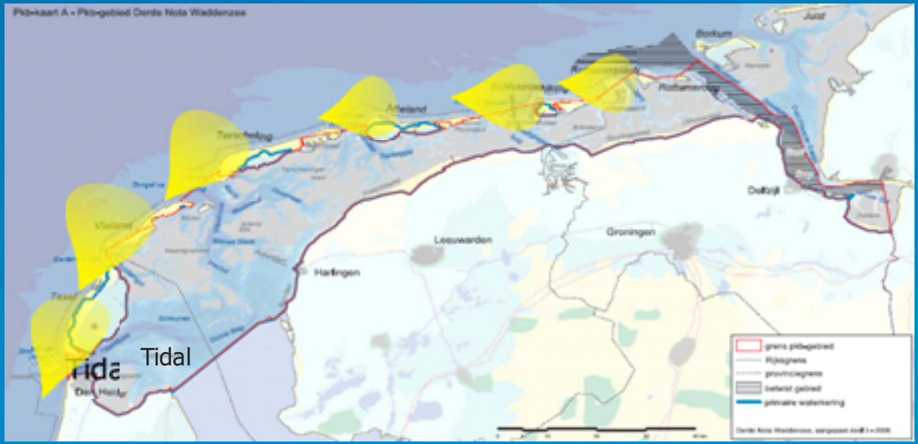
Option 3 a: protecting within existing boundaries, closed version”

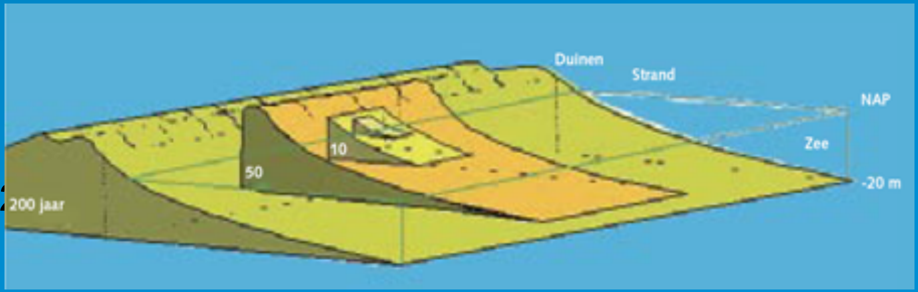


Option 3 b: protecting within existing boundaries, “open version”



Nourishment of the coastal sand-river





Images Courtesy RIKZ

Competing plan for the coastal defence in North Holland near den Helder.

De Hondsbossche zeewering van hard naar zacht


Examples of existing broad (super) dikes, "unbreakable dikes"

Overstroombare superbrede dijk in Japan

Brede dijk langs Wantij in Dordrecht met ook functie voor recreatie en natuur

Photograph of multifunctional flood defence in Hamburg, Germany

Create a new barrier (island)

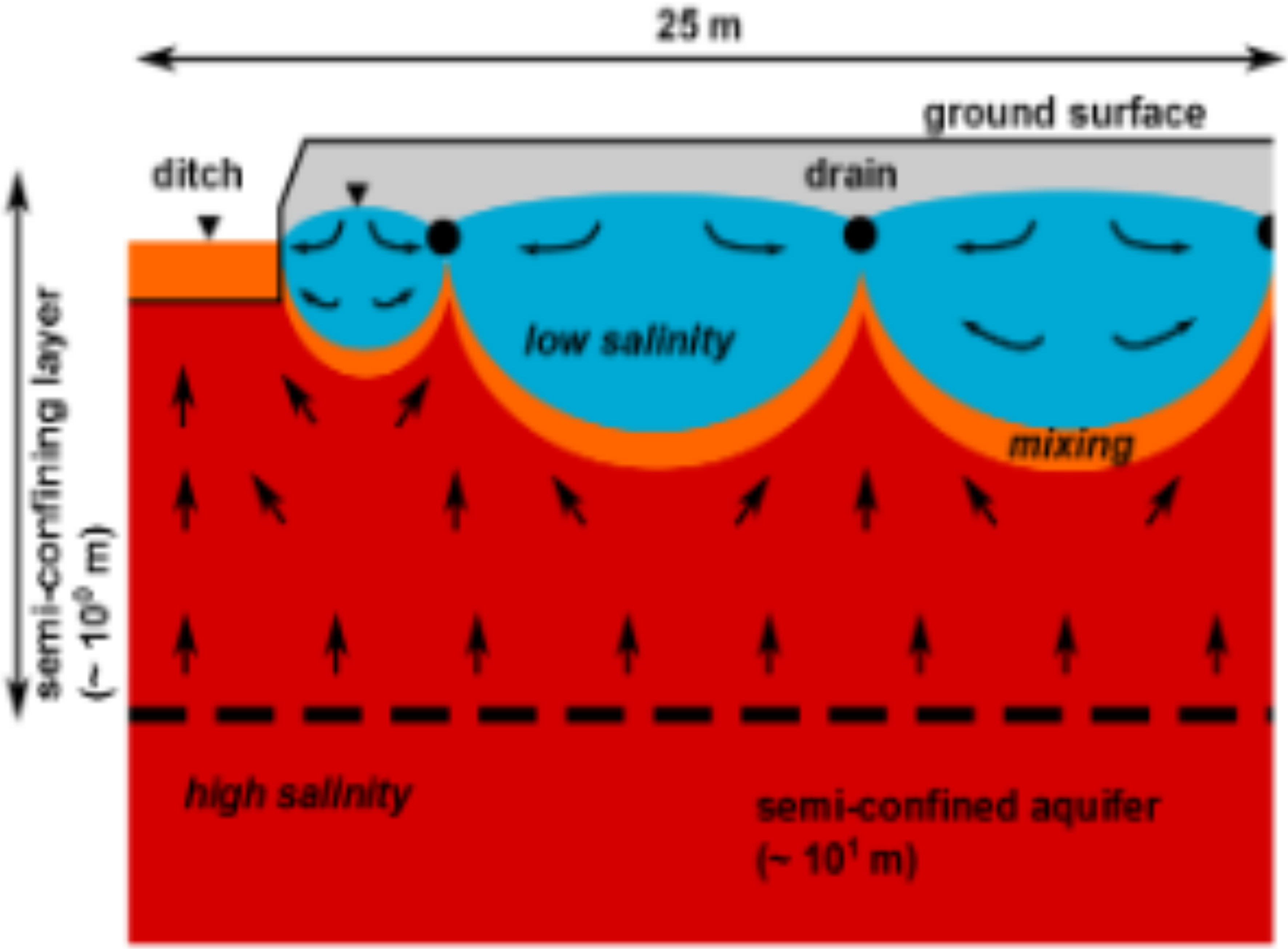
Cost of maintaining flood safety for the Netherlands

Now: about 2 billion euro per year
is about 0,4 % of GDP;

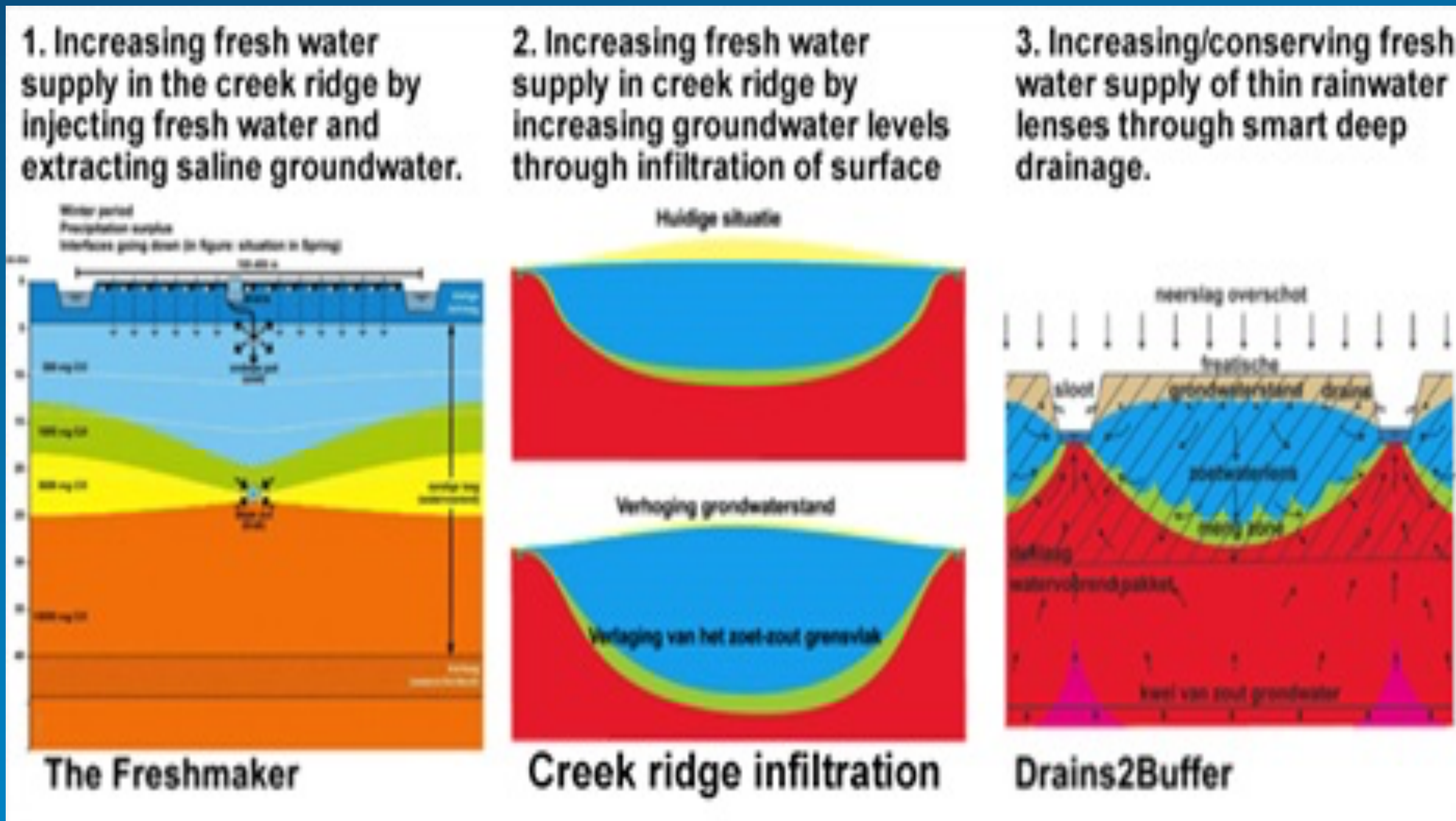
Additional: for a 1 meter sea level rise and higher river peak discharge is estimated at 2 billion per year, thus a doubling of annual cost from 0.4 to about 0.8 % of GDP.

A defensive strategy is feasible for the time being but…..

- Saline groundwater levels are rising through three mechanisms:
  - Drainage and lowering of groundwater table for agricultural production reasons brings geo-historic (relict) saline groundwater closer to the surface;
  - More persistant droughts due to climate change reduce the fresh water lens and bring saline groundwater closer to the surface
  - Sea level rise increases the saline groundwater pressure, thus pushing up the saline groundwater level upward;



25 m
ground surface
ditch
drain
low salinity
mixing
semi-confining layer
(~ 10⁰ m)
high salinity
semi-confined aquifer
(~ 10¹ m)



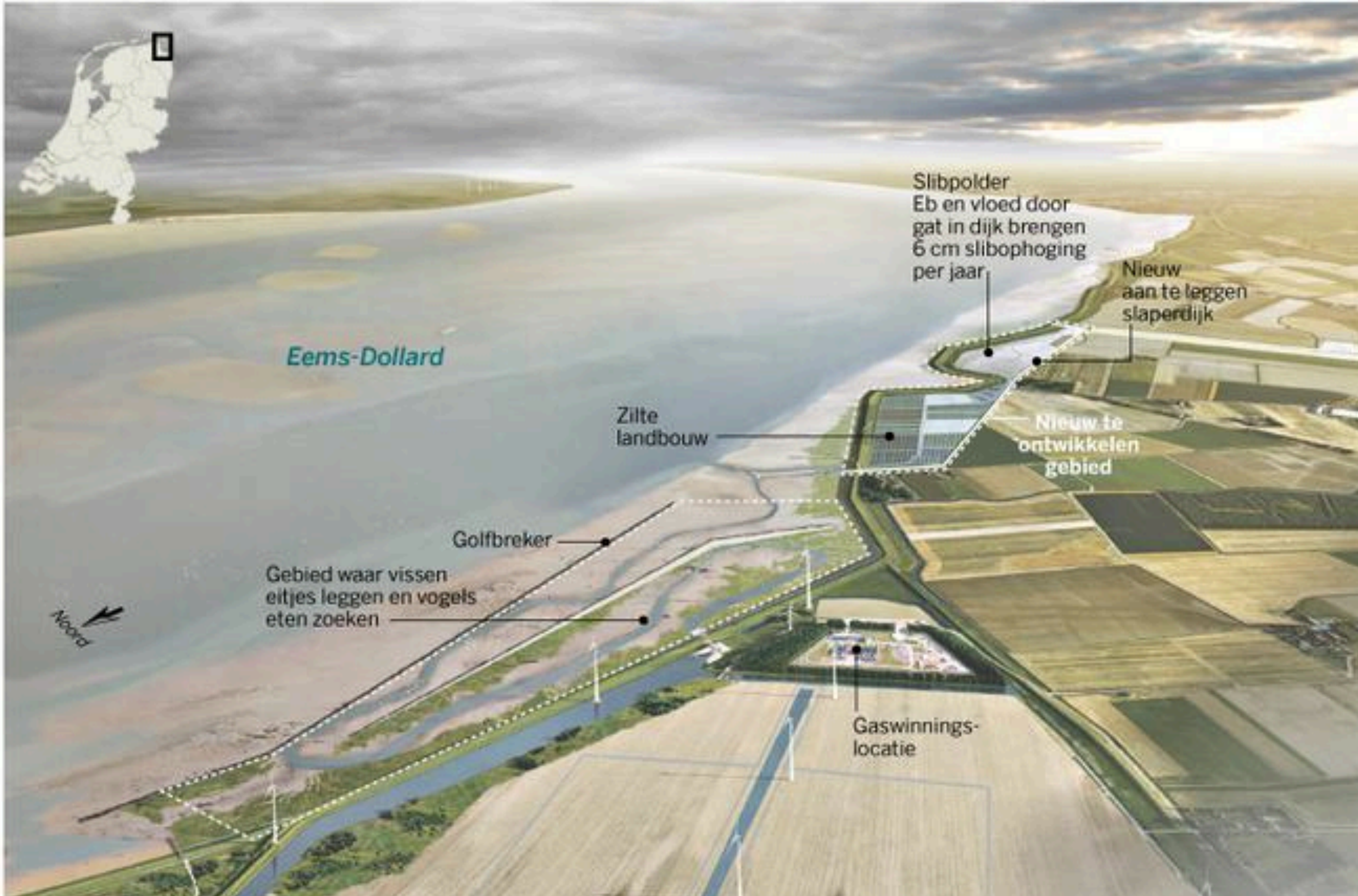
1. Increasing fresh water supply in the creek ridge by injecting fresh water and extracting saline groundwater.
2. Increasing fresh water supply in creek ridge by increasing groundwater levels through infiltration of surface
3. Increasing/conserving fresh water supply of thin rainwater lenses through smart deep drainage.
Huidige situatie
Verhoging grondwaterstand
Verlaging van het zoet-zout grensvlak
neerslag overschot
sloot
freatische
grondwaterstand
drains
kwel van zout grondwater
The Freshmaker
Creek ridge infiltration
Drains2Buffer

Four ways to produce food under more saline conditions

- Making existing fresh water crops more salt tolerant by breeding and selection: patatoes, carrots, tomatoes, oats, barley, etc..
- Market development for traditional halofytes like salicornia/sanfire, Cordgrass, Spiny Sea Plant, Papery Sea Bubble;
- Breeding of shell fish like cockles, other scallops, clams, mussels, oysters etc…within or outside the sea defence system
- Seaweeds;

PM presently world wide area of salinized soils is 1 billion ha. and growing.

Dubbele dijken aan de Dollard



060215 © de Volkskrant. Bron: Provincie Groningen

Saline agriculture

WHY?

WATER

98% salt water
and only 2% fresh,
1% is available

Shortage of fresh water

70% water use by agriculture

Produce **more** food
with **less** water

SALINIZATION

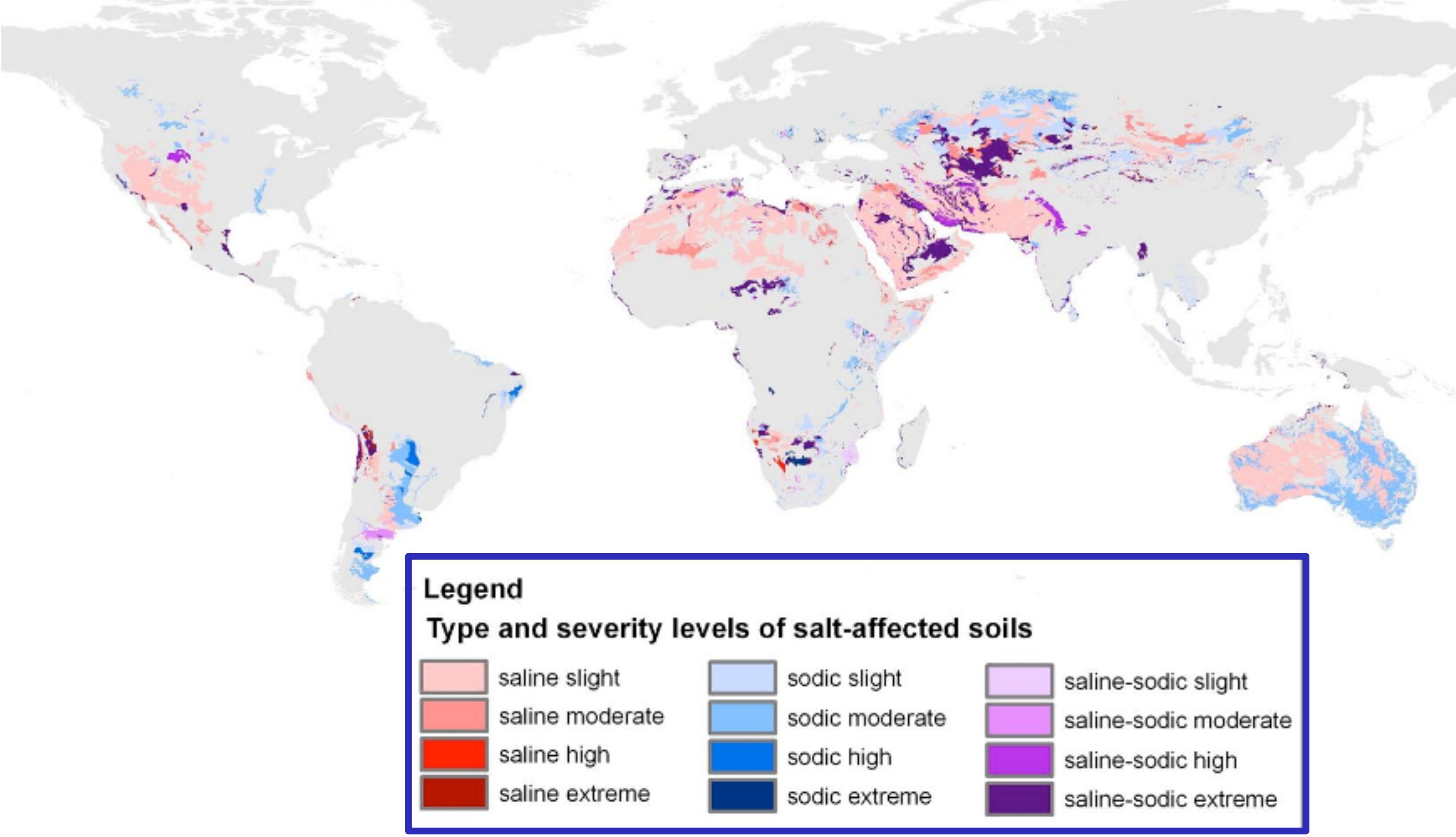
1 billion ha **salt affected**

Plus 3 ha **per minute**

$27 billion crop **salt damage**

SaltFarm Texel
Tested on Texel

Salt Farm FOUNDATION



Possibilities and opportunities for salt tolerant crops

Classification of salinity

Water class	EC (in dS/m)	in mg Cl^-/l	
Non-saline	< 0.7	< 150	Drinking and irrigation water
Slightly saline	0.7 - 2	150 - 480	Irrigation water
Moderately saline	2 - 10	480 - 2940	
Highly saline	10 - 25	2940 - 8250	
Very highly saline	25 - 45	8250 - 15970	
Brine	> 45	> 15970	Seawater=55 dS/m or 19,000 mg Cl^-/l

Soil salinity class	EC (in dS/m)	Effect on crop plants
Non-saline	0 - 2	Salinity effects negligible
Slightly saline	2 - 4	Yields of sensitive crops may be restricted
Moderately saline	4 - 8	Yields of many crops are restricted
Strongly saline	8 - 16	Only tolerant crops yield satisfactorily
Very strongly saline	> 16	Only a few very tolerant crops yield satisfactorily

Traditional agriculture: no growth beyond 1.7 dS/m
Can we find crops that can cross that threshold? (dS/m is deciSiemens per metre)

Open-air lab of Salt Farm Texel

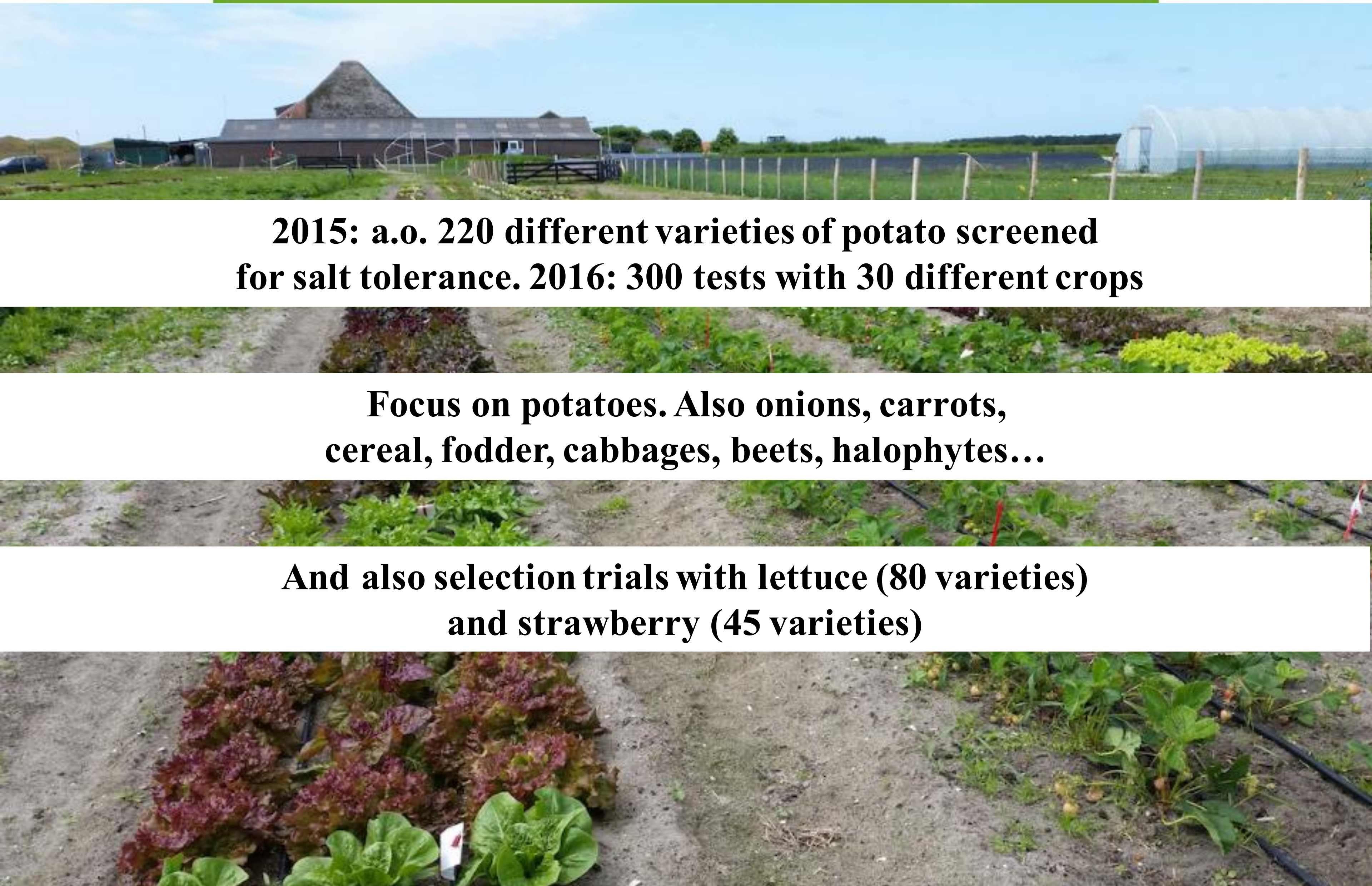
Determining exact level of salt tolerance

Salt Farm Texel - Test facility

7 salt concentrations, 8 repetitions, 56 plots of 160 m², 1 hectare total

1n	2n	3n	4n	5n	6n	7n	8n	9n	10n	11n	12n	13n	14n	15n	16n	17n	18n	19n	20n	21n	22n	23n	24n	25n	26n	27n	28n
35dS	16dS	4dS	20dS	16dS	35dS	0dS	12dS	8dS	4dS	20dS	4dS	16dS	8dS	0dS	20dS	16dS	35dS	0dS	8dS	20dS	12dS	8dS	12dS	4dS	16dS	8dS	4dS
schelpenpad																											
0dS	12dS	35dS	0dS	8dS	12dS	12dS	4dS	12dS	8dS	16dS	0dS	4dS	20dS	35dS	4dS	35dS	20dS	12dS	16dS	20dS	0dS	35dS	20dS	0dS	35dS	8dS	16dS
1z	2z	3z	4z	5z	6z	7z	8z	9z	10z	11z	12z	13z	14z	15z	16z	17z	18z	19z	20z	21z	22z	23z	24z	25z	26z	27z	28z

Ice plants in our foil greenhouse also cucumbers and tomatoes



2015: a.o. 220 different varieties of potato screened for salt tolerance. 2016: 300 tests with 30 different crops

Focus on potatoes. Also onions, carrots, cereal, fodder, cabbages, beets, halophytes…

And also selection trials with lettuce (80 varieties) and strawberry (45 varieties)

Potatoes
different varieties react different to salt

Potatoes
Still yield at half seawater

Same yield with carrots and onions

		Treshold for irrigation water, in dS/m		Treshold for irrigation water, in mg Cl-/l	
Crop	Variety	Treshold	Range	Treshold	Range *
Potato	Miss Mignonne	5.2	3.6 - 6.7	1411	933 - 1877
	Achilles	3.6	1.7 - 5.6	933	401 - 1534
	Foc	2.5	0.1 - 4.8	619	17 - 1290
	Met	2.2	0.0 - 4.6	537	0 - 1230
	927	4.2	2.1 - 6.5	1110	509 - 1814
	"Stuyt et al."	*3.7*		*838*	*500 - 1200*
Carrot	Cas	5.7	2.1 - 9.5	1565	509 - 2779
	Ner	4.5	0.4 - 8.5	1200	79 - 2452
	Nat	n.d.	n.d.	n.d.	n.d.
	Ben	n.d.	n.d.	n.d.	n.d.
	101	3.7	0.1 - 7.5	963	17 - 2130
	102	6.4	2.2 - 10.5	1782	537 - 3110
	Pri	2.5	0 - 7.7	619	0 - 2194
	"Stuyt et al."	*3.8*		*868*	*800 - 950*
Onion	Alo	2.9	0 - 9.9	732	0 - 2911
	Red	7.6	3.3 - 12.0	2162	846 - 3614
	San	4.0	0 - 9.3	1051	0 - 2713
	Hyb	4.2	0 - 10.4	1110	0 - 3077
	"Stuyt et al."	*3.8*		*867*	*875 - 1050*
Lettuce	Batavia, heading, red	n.d.	-	n.d.	-
	Butterhead, Suzan	2.8	0 - 11.3	704	0 - 3378
	Butterhead, Lob	2.1	0 - 14.0	509	0 - 4298
	"Stuyt et al."	*3.7*		*848*	*425 - 1300*
Cabbage	White cabbage, early	5.9	3.6 - 8.0	1627	933 - 2291
	"Stuyt et al."	*4.5*		*1093*	1025 - 1150
	Broccoli	7.2	1.3 - 13.2	2035	297 - 4022
	"Stuyt et al."	*2.9*		*600*	-
Barley	Que seed 2014	4.1	0 - 9.5	1080	0 - 2779
	Que shoot 2015	2.0	0 - 4.5	482	0 - 1200
	"Stuyt et al."	*8.9*		*2626*	*1150 - 4100*

Pakistan 2015-2016 season

Yield at 8 dS/m is around 30 tons/ha (50% higher than average)
Various locations also 50% water saving (usage of brackish water)
(picture taken in Sindh, Pakistan, saline sodic soil)

Bangladesh
Salt tolerant carrots, 2017

Bangladesh
Salt tolerant carrots, 2017

Ghana

In summary (1)

- Sea level rise very likely to accelerate in the years to come…..

- Maintaining a fresh water environment by reïnforcing coastal protection, fresh water flushing, pumping and selective draining… is feasible for the time being but costs are likely to increase considerably over time;

- In the longer run increasing crop damage must be expected due to rising saline ground water levels as a result of droughts and sea level rise and/or more frequent flooding by sea water;

In summary (2)

- Systematic tests and selection of crops has demonstrated that traditional type of crops can grow under more saline conditions than indicated by agricultural guidelines and general wisdom.

- Especially premium food products can succesfully be grown in present day moderately saline environments around the North Sea.

- Crop selection and knowledge on how to grow crops under moderately saline conditions and how to use and maintain soil fertility has an enormous world wide potential, for food and farmers income.

thank you for your attention