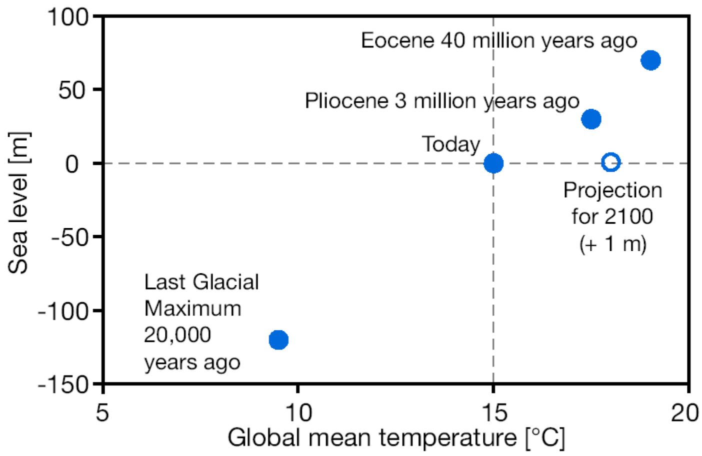
WWW.OZEAN-KLIMA.DE

Sea Level in a 4 ºC World

WWW.OZEAN-KLIMA.DE

Past Sea Level vs. Temperature

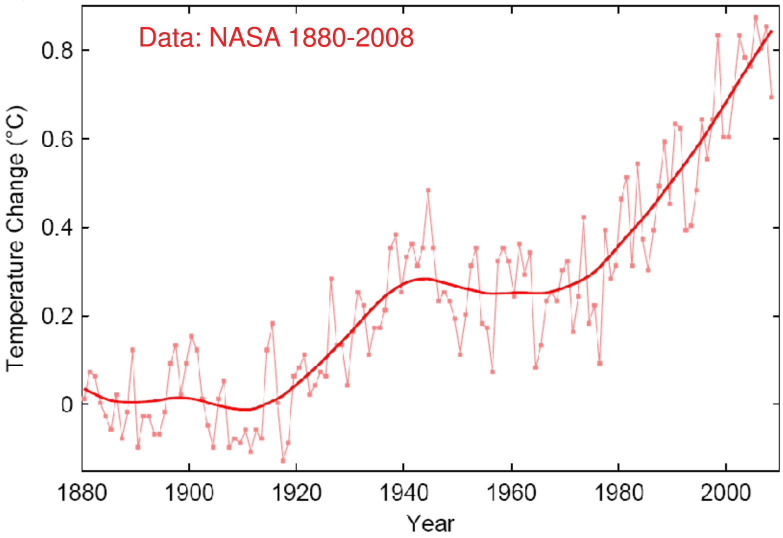


(WBGU, after Archer 2006)

2

WWW.OZEAN-KLIMA.DE

Observed Warming

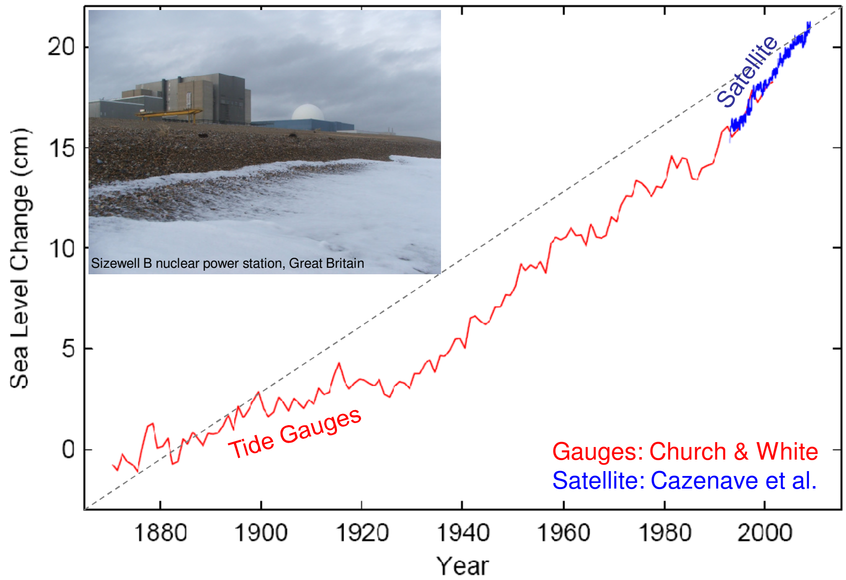


Increase in global mean surface temperature: ~0.8°C since 1900

3

WWW.OZEAN-KLIMA.DE

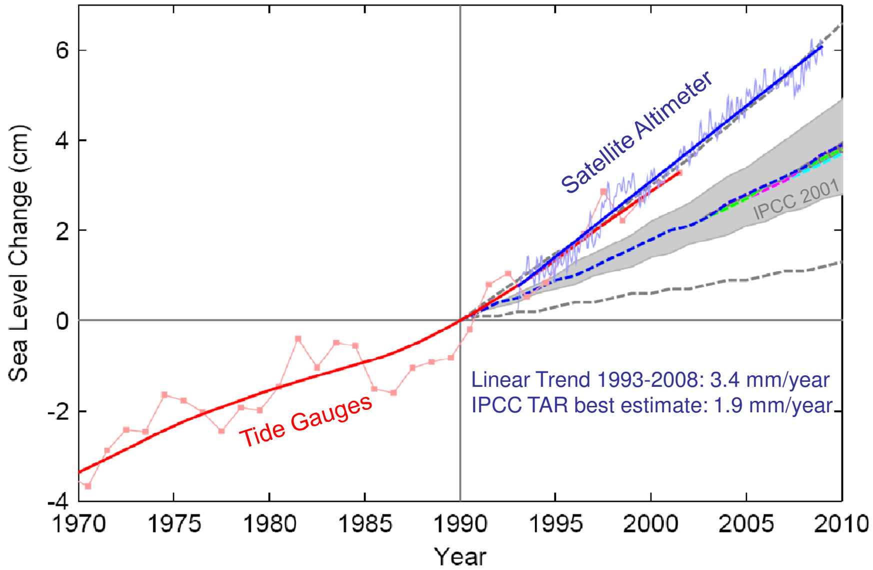
Sea Level Rise



WWW.OZEAN-KLIMA.DE

PIK

Rising Faster than Expected

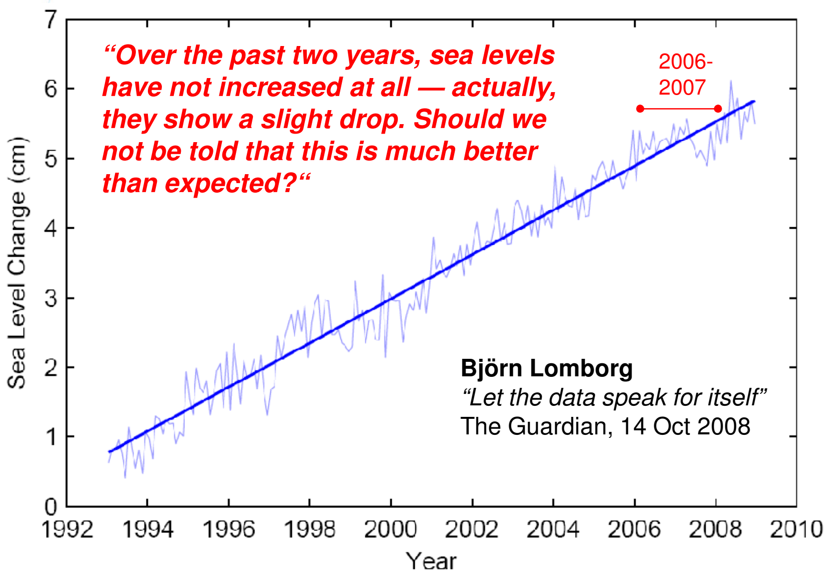


Updated from: Rahmstorf et al. Science 2007

WWW.OZEAN-KLIMA.DE

PIK

Or is it “much better than expected”?



6

A Semi-Empirical Approach to Projecting Future Sea-Level Rise

Science

Stefan Rahmstorf

A semi-empirical rela... temperature. It is pr... sea-level rise is roug... pre–Industrial Age. T... during the 20th cent... applied to future wa... relationship results i...

Simple first-order assumption about link between sea level and warming:

Rate of sea level rise proportional to warming (above pre-industrial background level)

$$dH/dt = a\,(T-T_0)$$

Understanding ... a difficult p... complex mec... scales play a role (1... sion of water due to the uptake and penetration of heat into the oceans, input of water into the ocean from glaciers and ice sheets, and changed water storage on land. Ice sheets have the largest potential effect, because their complete melting would result in a global sea-level rise of about 70 m. Yet their dynamics are poorly understood, and the key processes that control the response of ice flow to a warming climate are not included in current ice sheet models [for example, meltwater lubrication of the ice sheet bed (2) or increased ice stream flow after the removal of buttressing ice shelves (3)]. Large uncertainties exist even in the projection of thermal expansion, and estimates of the total volume of ice in mountain glaciers and ice caps that are remote from the continental ice sheets are uncertain by a factor of two (4). Finally, there are as yet no

future sea-level changes in response to a given surface warming scenario with present physics-based models is very limited, and models are not able to fully reproduce the sea-level rise of recent decades. Rates of sea-level rise calculated with climate and ice sheet models are generally lower than observed rates. Since 1990, observed sea level has followed the uppermost uncertainty limit of the Intergovernmental Panel on Climate Change (IPCC) Third Assessment Report (TAR), which was constructed by assuming the highest emission scenario combined with the highest climate sensitivity and adding an ad hoc amount of sea-level rise for "ice sheet uncertainty" (1).

While process-based physical models of sea-level rise are not yet mature, semi-empirical models can provide a pragmatic alternative to estimate the sea-level response. This is also the

tion of the sea-level response from first principles is so complex that semi-empirical relationships perform better. Likewise, with current and future sea-level rise, the driver is known [global warming (1)], but the computation of the link between the driver and the response from first principles ...ll explore a semi- ...g sea-level rise. ...he global average ...which is the stan- ...ibe global warm- ...atic response to a ...emperature, after ...ters were at equi- ...o rise as the ocean ...ts to melt, until ...brium sea level is ...ggest that changes ...may be very large: ... Maximum, about 20,000 years ago, was 120 m lower than the current level, whereas global mean temperature was 4° to 7°C lower (5, 6). Three million years ago, during the Pliocene, the average climate was about 2° to 3°C warmer and sea level was

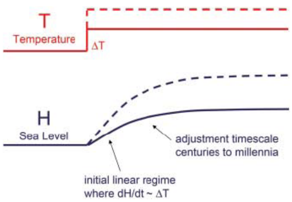
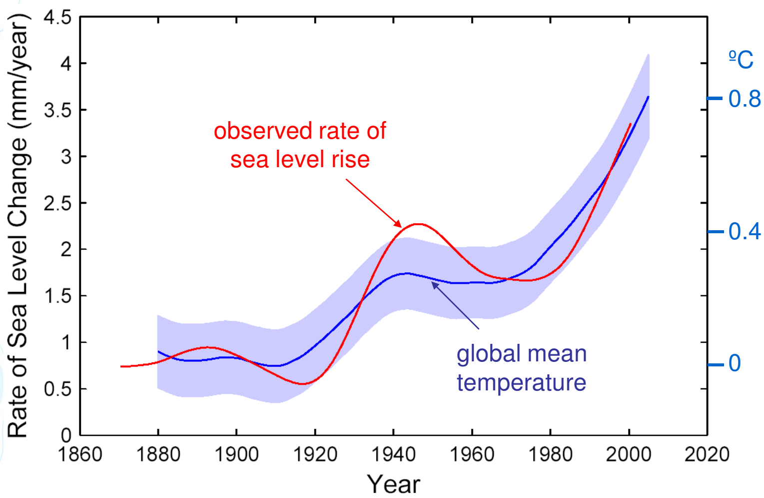


Fig. 1. Schematic of the response of sea level

WWW.OZEAN-KLIMA.DE

Sea level response to temperature



8

Rahmstorf, Science 2007

A Semi-Empirical Approach to Projecting Future Sea-Level Rise

Science

Stefan Rahmstorf

tion of the sea-level response from first principles is so complex that semi-empirical relationships perform better. Likewise, with current and future sea-level rise, the driver is known [global warming (1)], but the computation of the link between the driver and the response from first principles

Simple first-order assumption about link between sea level and warming:

Rate of sea level rise proportional to warming (above pre-industrial background level)

$$dH/dt = a\,(T-T_0)$$

future sea-level changes in response to a given surface warming scenario with present physics-based models is very limited, and models are not able to fully reproduce the sea-level rise of recent

20,000 years ago, was 120 m lower than the current level, whereas global mean temperature was 4° to 7°C lower (5, 6). Three million years ago, during the Pliocene, the average climate

Modification proposed by Martin Vermeer:

Add fast-response term

$$dH/dt = a\,(T-T_0) + b\,dT/dt$$

mountain glaciers and ice caps that are remote from the continental ice sheets are uncertain by a factor of two (4). Finally, there are as yet no

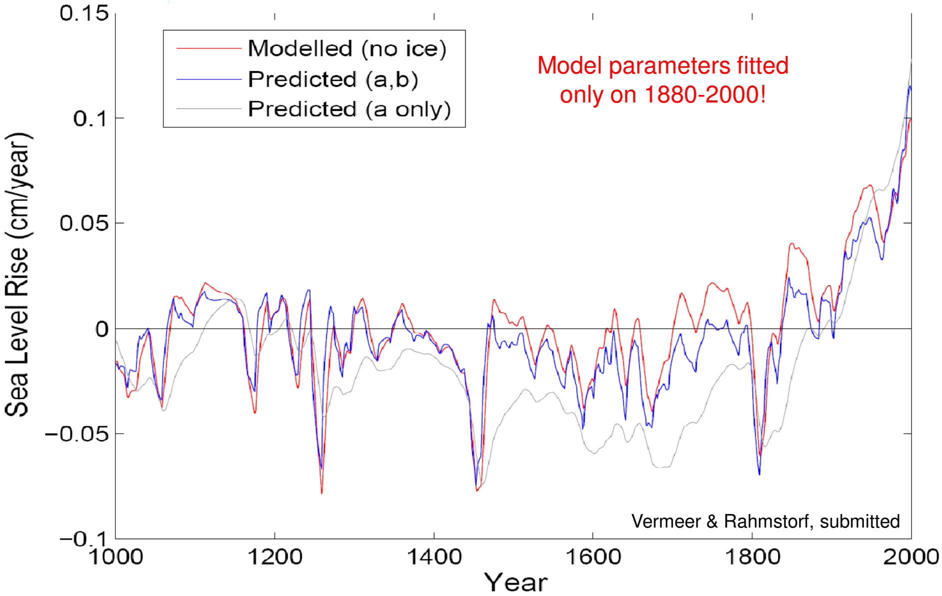
level rise are not yet mature, semi-empirical models can provide a pragmatic alternative to estimate the sea-level response. This is also the

initial linear regime where dH/dt ~ ΔT

Fig. 1. Schematic of the response of sea level

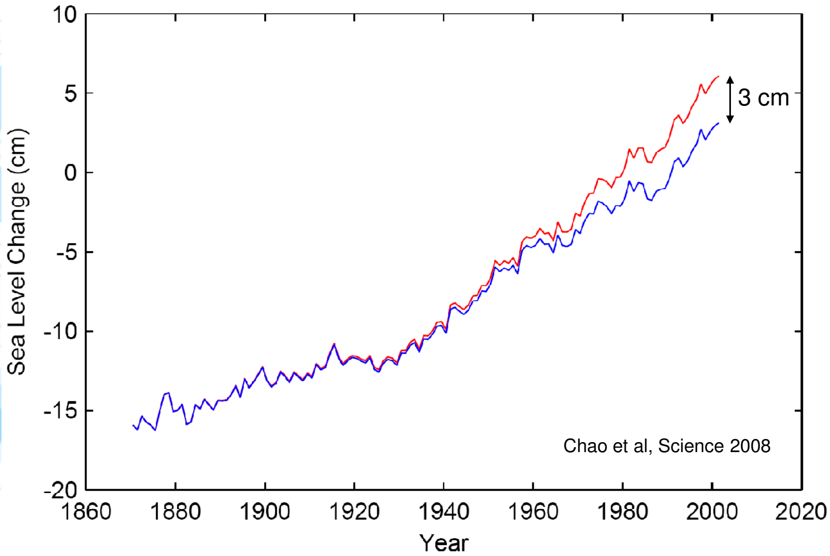
WWW.OZEAN-KLIMA.DE

Test: Simulation of past millennium



WWW.OZEAN-KLIMA.DE

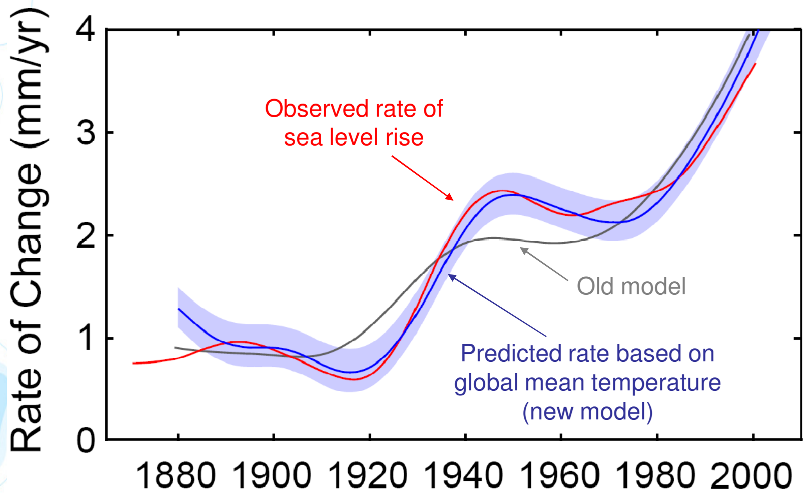
Reservoir correction



11

WWW.OZEAN-KLIMA.DE

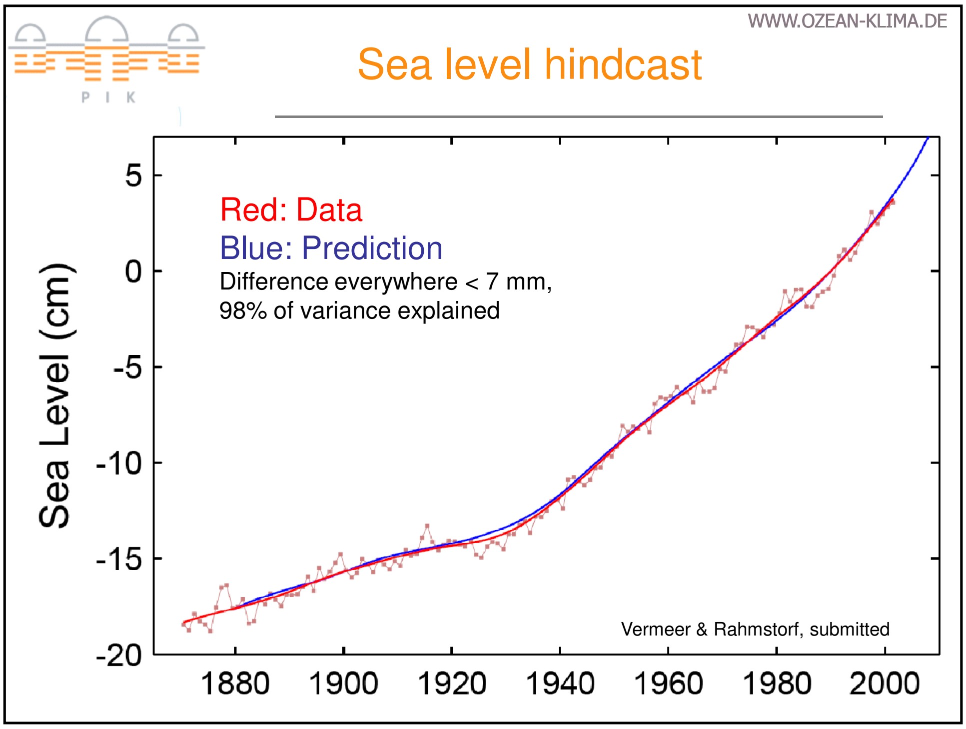
Test: Observational data

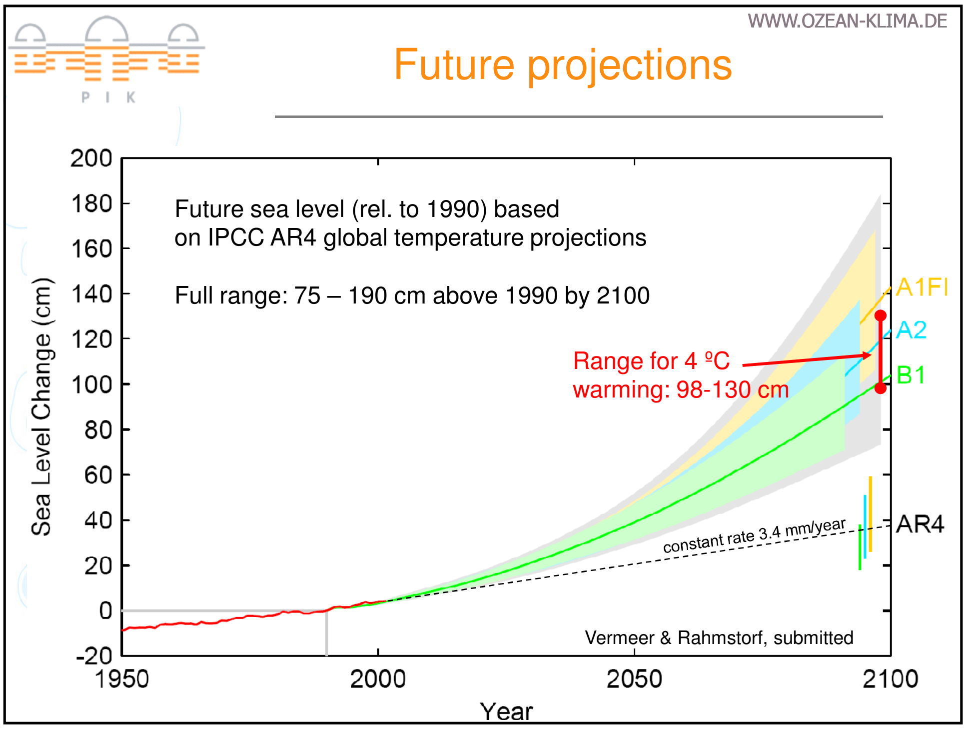


Data: Church & White sea level with Chao reservoir correction
NASA GISS global mean temperature

Vermeer & Rahmstorf, submitted

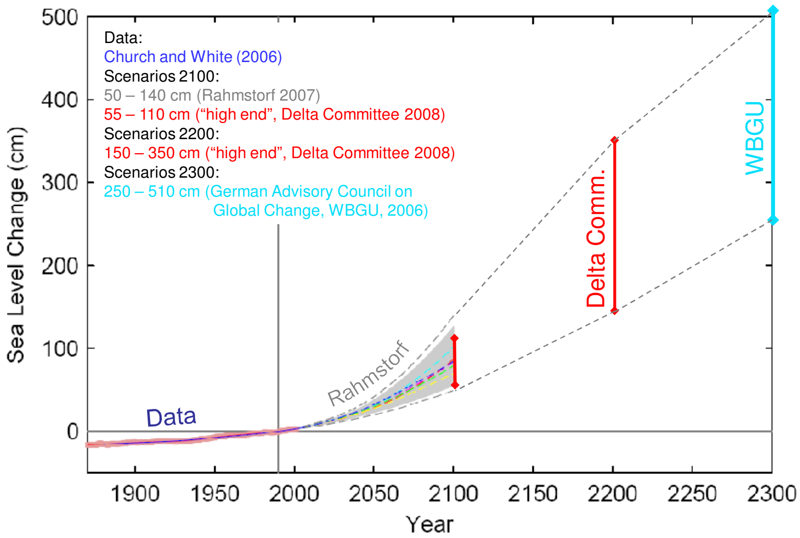
12


WWW.OZEAN-KLIMA.DE
P I K
Sea level hindcast
Red: Data
Blue: Prediction
Difference everywhere < 7 mm,
98% of variance explained
Sea Level (cm)
5
0
-5
-10
-15
-20
1880
1900
1920
1940
1960
1980
2000
Vermeer & Rahmstorf, submitted


WWW.OZEAN-KLIMA.DE
P I K
Future projections
Future sea level (rel. to 1990) based
on IPCC AR4 global temperature projections
Full range: 75 – 190 cm above 1990 by 2100
Range for 4 ºC
warming: 98-130 cm
A1FI
A2
B1
AR4
constant rate 3.4 mm/year
Sea Level Change (cm)
200
180
160
140
120
100
80
60
40
20
0
-20
1950
2000
2050
2100
Year
Vermeer & Rahmstorf, submitted

WWW.OZEAN-KLIMA.DE

Other recent sea level projections



15

WWW.OZEAN-KLIMA.DE

Conclusions

- Sea level is rising: 20 cm since 1880
- Since 1993 3.4 mm/yr
- Future rise rather uncertain – at 4 ºC above preindustrial, semi-empirical approach gives 1 – 1.3 meters by 2100
- Over several centuries, several meters can be expected

16


Thanks for Listening!
THE SUSTAINABILITY PROJECT
Stefan Rahmstorf
Katherine Richardson
OUR THREATENED OCEANS
Foto: S. Rahmstorf