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Supplement of

Delaying future sea-level rise by storing water on Antarctica

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1 **S1 Efforts of delaying sea level rise in comparison to local adaptation**

2 Storing ocean water 700km inland on the Antarctic Ice Sheet requires overcoming a height
3 difference of about 4000m. Mitigating a sea-level rise of 3 mm yr⁻¹ requires 1275 GW of
4 power to increase the potential energy of the water accordingly. This corresponds to a
5 power of 10 kW that is required to pump 1 m³/s vertically to a height of 1m. The actual
6 energy required for the pumping will be higher due to friction and inefficient pumping. Here
7 we assume a required power of 18 kW to pump 1 m³/s to a height of 1m. This value is
8 based on the project Tagus-Segura Water Transfer¹. In its first section (TRAMO I) a power of
9 135 MW is applied to achieve a through-put of 31.7 m³/s over a height difference of 245 m,
10 which corresponds to 17.3 kW/(m³/s)/m. This would mean that the required power to
11 mitigate a sea-level rise of 3 mm yr⁻¹ would reach about 2300 GW. To avoid further
12 greenhouse-gas emissions the power would have to be generated based on local renewable
13 technologies.

14

15 That poses a fundamental engineering problem that goes far beyond the scope of existing
16 projects. While wind power plants and pipeline technology readily exist, currently the
17 required technology is not available for the very low temperatures of Antarctica, as far as
18 we know. We cannot provide reliable estimates of the associated costs at this stage.

19

20 However, to put the engineering effort into perspective we here compare the technical
21 requirements of the pumping and transporting system to that of the Trans Alaska Pipeline
22 (TAP)². Thereby we assume that the transport of the water is split up into 90 individual
23 pipelines each ensuring a throughput of $11 \cdot 10^9 \text{ m}^3 \text{ yr}^{-1}$ as provided by the largest New
24 Orleans pumping station.

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	Trans Alaska Pipeline	Individual pipeline of the potential Antarctic pumping system
Length	1287 km	700 km
Maximum elevation	1444 m	4000 m
Air temperature along route	-60°C to 35°C	far below 0°C
Annual throughput	0.1245 · 10 ⁹ m ³ (assuming a maximum daily throughput as reached in 1988)	11 · 10 ⁹ m ³

28

29 The costs of building the TAP amount to a total of 8 billion US\$. On the one hand this
30 includes costs not relevant for the Antarctic pipelines and pumps such as:

- 31 • costs of the Valdez oil terminal (US\$1.4)
- 32 • launching/receiving facilities for cleaning pigs that sweep the pipe of built-up wax,
33 water or other solids that precipitate out of the oil stream
- 34 • 124,300 heat pipes along the pipeline transferring ground heat into the air during
35 cold periods to lower the ground temperature to ensure that soils remain frozen
36 throughout the summer to steadily support the pipeline (to be replaced by
37 alternatives adequate for Antarctica).

38

39 While on the other hand the Antarctic systems will

- 40 • have to provide an orders of magnitude higher throughput (assuming 90 individual
41 lines starting at the ocean with an annual throughput of 11 · 10⁹ m³ as provided by
42 the largest New Orleans pump station would require an upscaling of the maximum
43 annual throughput of the TAP (calculated based on its maximum daily throughput
44 reached in 1988) by a factor of 90 for each individual line).
- 45 • have to overcome a larger elevation difference (4000m in comparison to a maximum
46 of 1444 m along the TAP)
- 47 • require heating along the pipelines

- 48 • require a system to distribute the water on the ice sheet
- 49 • need an adjustments of the pipeline due to moving ice

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51 to provide a simplistic upscaling of the TAP costs excluding the terminal (6.6 US\$) to the
 52 required length (L), height (H), and capacity (P) we assume that the overall costs C can be
 53 split up in to components, a first one C_1 that scales with P and H (mainly representing the
 54 costs of the pump stations) and a second one C_2 that scales with L and P (mainly
 55 representing the costs of the pipeline itself). Assume that the two components of the
 56 overall costs of the TAB C_{TAB} are given by $C_{1,TAP} = \alpha C_{TAP}$ and accordingly $C_{2,TAP} = (1-\alpha) C_{TAP}$
 57 that would mean that

58

$$C = C_{1,TAB} * \frac{P}{P_{TAB}} * \frac{H}{H_{TAB}} + C_{2,TAB} * \frac{P}{P_{TAB}} * \frac{L}{L_{TAB}}$$

59

$$\approx \alpha 6.6 * 10^{12} \text{ US\$} * 8015 * 3 + (1 - \alpha) 6.6 * 10^{12} \text{ US\$} * 8015 * 50$$

60

61 with $C = 158,697$ billion US\$ for $\alpha = 1$ and $C = 2,644,950$ billion US\$ for $\alpha = 0$. Both numbers
 62 do not include the costs of running and maintaining the system. Assuming they are minor
 63 compared to the cost of construction, construction costs could be divided by 100 to
 64 estimate the annual costs over the 21st century. In both cases they are orders of magnitude
 65 higher than the estimated annual investment and maintenance costs of local adaptation by
 66 dikes of US\$ 12–71 billion in 2100³ which however only protects regions that are
 67 economically expendent to protect. This might exclude for example the AOSIS small island
 68 states and their culture as well as UNESCO cultural heritage sites⁴.

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70 That means that such a project would only become competitive with major efficiency gains
 71 by technical innovations and learning from the experience of the project itself.

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75 **S2 Wind Energy potential in Antarctica**

76 We follow the methodology of ref. 5 to estimate the wind energy that is available in a 200
 77 km wide band along the East Antarctic coast (Fig. S1). We use the yearly mean wind data for
 78 2014 at 10m above the surface from the Era-Interim dataset⁶. Following ref. 5, we use only
 79 regions with average wind speed above 6.5 m/s. The power of a single wind turbine can be
 80 estimated by (ref. 5, equ. 19):

81

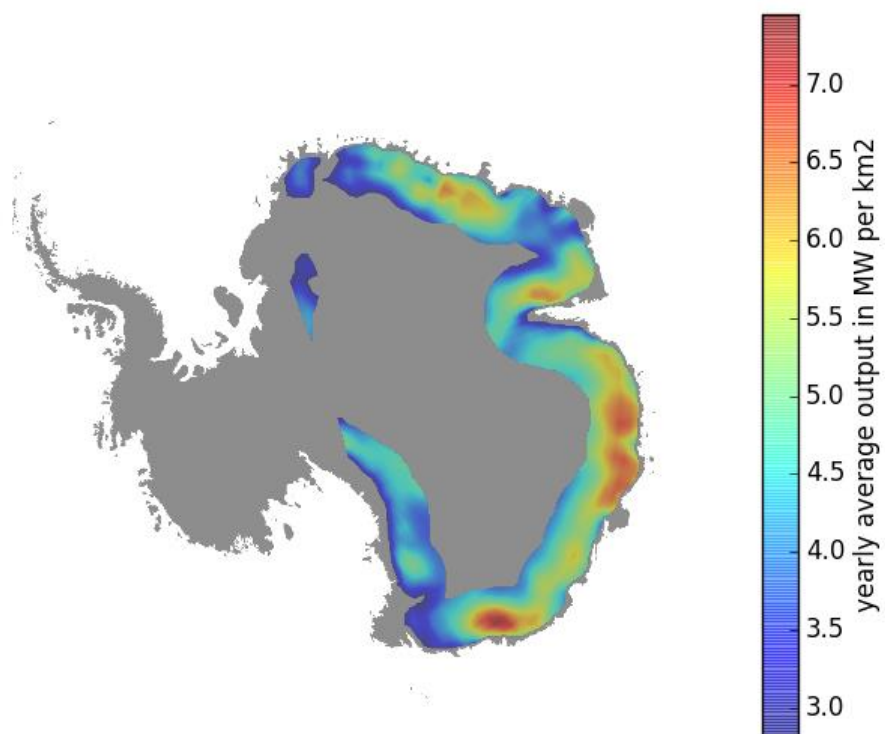
$$P = P_{rated} * CF = P_{rated} * (0.087V - \frac{P_{rated}}{D^2})$$

82

83 with P as average power output, P_{rated} the rated power of a single wind turbine, CF the
 84 conversion factor, V the average yearly wind speed and D the rotor diameter of the wind
 85 turbine. Six wind turbines of the 1.5 MW class can be installed per square kilometre⁵.
 86 Integrating over the East Antarctic band area with wind stronger than 6.5 m/s, we estimate
 87 a wind power potential of 16.7 TW. Regions difficult to access, such as mountain ranges,
 88 and regions of fast flowing ice have not been excluded from the total area. We do not apply
 89 a conversion of 10m above-surface winds to such at the height of the rotor (80m in ref. 5).
 90 As winds at 80m are generally higher than at 10m above the surface, the real wind energy
 91 potential may be higher.

92 Wind power utilization in Antarctica will pose a number of major challenges that cannot be
 93 addressed here. These include building fundamentals on moving and deformable ground,
 94 functioning under extremely cold temperatures in Antarctic winters and handling very high
 95 wind velocities.

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97

98 **Fig. S1: Wind energy potential in East Antarctica.** Using ERA-Interim data⁶, we use the
99 methodology of ref. 5 to estimate the wind power potential in a 200km-wide strip along the
100 East Antarctic coast. High wind speeds above 6.5 m/s on yearly average in the major part of
101 the strip allow for large-scale wind energy extraction.

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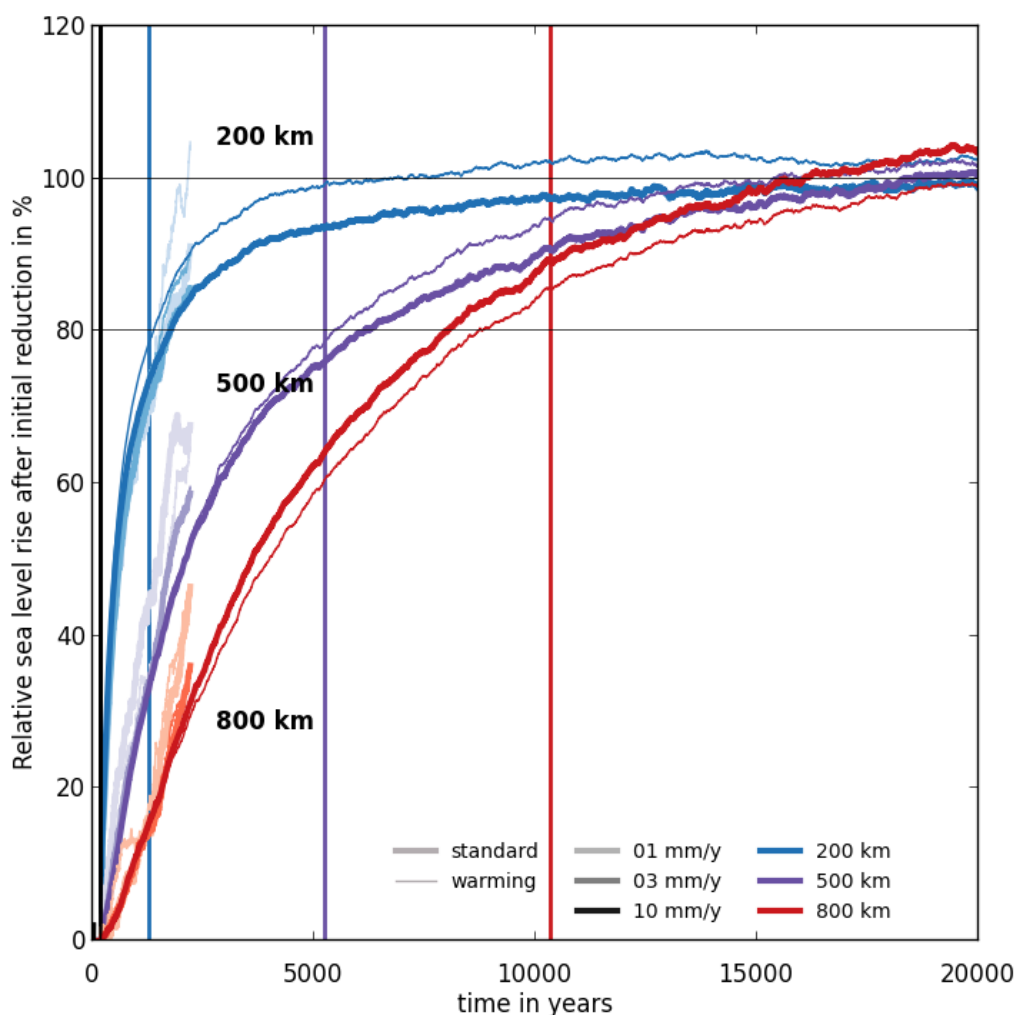
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108 **S3 Long term response**

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110 **Fig. S2: Delayed sea-level rise as fraction of the initial reduction.** Colour coding indicates
 111 the application band where the ice is added (red: 800 km distance from the coast, violet:
 112 500 km distance from the coast, and blue: 200 km distance from the coast). The colour
 113 intensity describes the application rate from 1 mm yr^{-1} (light), via 3 mm yr^{-1} (normal) to 10 mm yr^{-1}
 114 mm yr^{-1} (dark). Thin lines show the results of the simulations accounting for latent-heat
 115 release while thick lines represent the results without the additional warming. Vertical lines
 116 mark the 5th percentile of the distribution of delay times assuming an ice parcel traveling
 117 800 km (red), 500 km (violet), and 200 km (blue) with a constant surface velocity drawn
 118 from the distribution of surface velocities observed within the area of less than 800 km, 500

119 km and 200 km distance from the coast. Real advection of ice particles to the coast by the
120 surface velocities will even take longer because generally the ice will not be flowing the
121 direct path assumed here.

122

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