

# *Optimization/simulation-based risk mitigation in resilient green communication networks*

## Code for optimization procedures

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To reproduce the steps of the algorithm presented in the paper, save attached files to a common directory and provide required tools.

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## SOFTWARE REQUIREMENTS

- CPLEX (including OPL Interpreter): <http://www-01.ibm.com/software/commerce/optimization/cplex-optimizer/>

## NR-POLAND.DAT

This CPLEX file presents data necessary to find the optimal optical flows if energy profiles in links are concave. The recovery option used by all the demands is a lack of recovery NR. The energy profiles are approximated with linear segments. The data is related to the Poland network

```

1 // *****/
2 // OPL 12.6.0.0 Model
3 // Author: Piotr Cholda, AGH University of Science and Technology
4 // piotr.cholda@agh.edu.pl
5 // Creation Date: 2 June 2015
6 // *****/
7
8 Nodes = {Gdansk,
9         Bydgoszcz,
10        Kolobrzeg,
11        Katowice,
12        Krakow,
13        Bialystok,
14        Lodz,
15        Poznan,
16        Rzeszow,
17        Szczecin,
18        Warsaw,
19        Wroclaw};
20
21 Arcs = {<Gdansk,Warsaw>, <Gdansk,Kolobrzeg>,
22        <Bydgoszcz,Kolobrzeg>, <Bydgoszcz,Poznan>,
23        <Bydgoszcz,Warsaw>, <Kolobrzeg,Szczecin>,
24        <Katowice,Krakow>, <Katowice,Lodz>,
25        <Katowice,Wroclaw>, <Krakow,Rzeszow>,
26        <Krakow,Warsaw>, <Bialystok,Rzeszow>,
27        <Bialystok,Warsaw>, <Lodz,Warsaw>,
28        <Lodz,Wroclaw>, <Poznan,Szczecin>,
29        <Poznan,Wroclaw>, <Gdansk,Bialystok>};
30
31 Demands = {<Gdansk,Bydgoszcz>, <Gdansk,Kolobrzeg>,
32            <Gdansk,Katowice>, <Gdansk,Krakow>,
33            <Gdansk,Bialystok>, <Gdansk,Lodz>,
34            <Gdansk,Poznan>, <Gdansk,Rzeszow>,
35            <Gdansk,Szczecin>, <Gdansk,Warsaw>,
36            <Gdansk,Wroclaw>, <Bydgoszcz,Kolobrzeg>,
37            <Bydgoszcz,Katowice>, <Bydgoszcz,Krakow>,
38            <Bydgoszcz,Bialystok>, <Bydgoszcz,Lodz>,
39            <Bydgoszcz,Poznan>, <Bydgoszcz,Rzeszow>,
40            <Bydgoszcz,Szczecin>, <Bydgoszcz,Warsaw>,
41            <Bydgoszcz,Wroclaw>, <Kolobrzeg,Katowice>,
42            <Kolobrzeg,Krakow>, <Kolobrzeg,Bialystok>,
43            <Kolobrzeg,Lodz>, <Kolobrzeg,Poznan>,
44            <Kolobrzeg,Rzeszow>, <Kolobrzeg,Szczecin>,
45            <Kolobrzeg,Warsaw>, <Kolobrzeg,Wroclaw>,
46            <Katowice,Krakow>, <Katowice,Bialystok>,
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49            <Katowice,Warsaw>, <Katowice,Wroclaw>,
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56            <Bialystok,Wroclaw>, <Lodz,Poznan>,
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61            <Rzeszow,Szczecin>, <Rzeszow,Warsaw>,
62            <Rzeszow,Wroclaw>, <Szczecin,Warsaw>,
63            <Szczecin,Wroclaw>, <Warsaw,Wroclaw>};
64

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    ↵ 168 119 127 105 147 140 198 104 113 169 187 196 193 151 106 125 194 194 123 181 193 181↵
    ↵ 195 141];

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66 Path = 10;

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↳5.286641e-03 5.283689e-03 5.280741e-03 5.277798e-03 5.274861e-03 5.271928e-03 ↵
↳5.269000e-03 5.266076e-03 5.263158e-03 5.260245e-03 5.257336e-03 5.254432e-03 ↵
↳5.251533e-03 5.248639e-03 5.245750e-03 5.242865e-03 5.239985e-03 5.237110e-03 ↵
↳5.234239e-03 5.231374e-03 5.228513e-03 5.225656e-03 5.222805e-03 5.219958e-03 ↵
↳5.217115e-03 5.214278e-03 5.211445e-03 5.208616e-03 5.205792e-03 5.202973e-03 ↵
↳5.200158e-03 5.197348e-03 5.194543e-03 5.191742e-03 5.188945e-03 5.186153e-03 ↵
↳5.183365e-03 5.180582e-03 5.177804e-03 5.175030e-03 5.172260e-03 5.169495e-03 ↵
↳5.166734e-03 5.163978e-03 5.161226e-03 5.158479e-03 5.155735e-03 5.152997e-03 ↵
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↳5.117785e-03 5.115106e-03 5.112432e-03 5.109761e-03 5.107095e-03 5.104433e-03 ↵
↳5.101775e-03 5.099122e-03 5.096472e-03 5.093827e-03 5.091185e-03 5.088548e-03 ↵
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↳5.054633e-03 5.052052e-03 5.049475e-03 5.046902e-03 5.044333e-03 5.041768e-03 ↵
↳5.039207e-03 5.036649e-03 5.034096e-03 5.031546e-03 5.029001e-03 5.026459e-03 ↵
↳5.023921e-03 5.021387e-03 5.018856e-03 5.016330e-03 5.013807e-03 ];

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92

93

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Coeff_b = [ 0 1.852419e+00 2.461957e+00 2.935236e+00 3.338505e+00 3.696573e+00 4.022165e+00
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↳+00 5.806485e+00 6.018111e+00 6.222520e+00 6.420404e+00 6.612353e+00 6.798872e+00
↳ 6.980398e+00 7.157313e+00 7.329952e+00 7.498611e+00 7.663553e+00 7.825015e+00 ↵
↳7.983208e+00 8.138324e+00 8.290534e+00 8.439997e+00 8.586857e+00 8.731244e+00 ↵
↳8.873281e+00 9.013078e+00 9.150738e+00 9.286356e+00 9.420021e+00 9.551814e+00 ↵
↳9.681813e+00 9.810088e+00 9.936706e+00 1.006173e+01 1.018522e+01 1.030723e+01 ↵
↳1.042781e+01 1.054701e+01 1.066488e+01 1.078146e+01 1.089679e+01 1.101092e+01 ↵
↳1.112387e+01 1.123569e+01 1.134640e+01 1.145605e+01 1.156465e+01 1.167225e+01 ↵
↳1.177886e+01 1.188452e+01 1.198924e+01 1.209306e+01 1.219599e+01 1.229806e+01 ↵

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↳1.239929e+01	1.249970e+01	1.259931e+01	1.269814e+01	1.279620e+01	1.289352e+01	↳
↳1.299011e+01	1.308599e+01	1.318117e+01	1.327567e+01	1.336950e+01	1.346267e+01	↳
↳1.355521e+01	1.364711e+01	1.373841e+01	1.382910e+01	1.391919e+01	1.400871e+01	↳
↳1.409766e+01	1.418606e+01	1.427390e+01	1.436121e+01	1.444799e+01	1.453425e+01	↳
↳1.462000e+01	1.470526e+01	1.479002e+01	1.487430e+01	1.495810e+01	1.504144e+01	↳
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↳1.561234e+01	1.569220e+01	1.577166e+01	1.585072e+01	1.592939e+01	1.600767e+01	↳
↳1.608557e+01	1.616309e+01	1.624024e+01	1.631703e+01	1.639346e+01	1.646954e+01	↳
↳1.654526e+01	1.662064e+01	1.669568e+01	1.677039e+01	1.684476e+01	1.691880e+01	↳
↳1.699253e+01	1.706593e+01	1.713902e+01	1.721180e+01	1.728427e+01	1.735644e+01	↳
↳1.742831e+01	1.749989e+01	1.757118e+01	1.764217e+01	1.771288e+01	1.778332e+01	↳
↳1.785347e+01	1.792335e+01	1.799295e+01	1.806229e+01	1.813137e+01	1.820018e+01	↳
↳1.826873e+01	1.833703e+01	1.840507e+01	1.847286e+01	1.854040e+01	1.860770e+01	↳
↳1.867476e+01	1.874158e+01	1.880815e+01	1.887450e+01	1.894061e+01	1.900649e+01	↳
↳1.907215e+01	1.913758e+01	1.920278e+01	1.926777e+01	1.933253e+01	1.939708e+01	↳
↳1.946142e+01	1.952555e+01	1.958946e+01	1.965317e+01	1.971667e+01	1.977996e+01	↳
↳1.984306e+01	1.990595e+01	1.996865e+01	2.003115e+01	2.009346e+01	2.015557e+01	↳
↳2.021750e+01	2.027923e+01	2.034078e+01	2.040214e+01	2.046331e+01	2.052431e+01	↳
↳2.058512e+01	2.064576e+01	2.070621e+01	2.076649e+01	2.082660e+01	2.088653e+01	↳
↳2.094630e+01	2.100589e+01	2.106531e+01	2.112457e+01	2.118366e+01	2.124258e+01	↳
↳2.130135e+01	2.135995e+01	2.141839e+01	2.147667e+01	2.153480e+01	2.159276e+01	↳
↳2.165058e+01	2.170824e+01	2.176574e+01	2.182310e+01	2.188030e+01	2.193736e+01	↳
↳2.199426e+01	2.205102e+01	2.210764e+01	2.216411e+01	2.222043e+01	2.227662e+01	↳
↳2.233266e+01	2.238856e+01	2.244432e+01	2.249995e+01	2.255544e+01	2.261079e+01	↳
↳2.266600e+01	2.272109e+01	2.277603e+01	2.283085e+01	2.288554e+01	2.294009e+01	↳
↳2.299452e+01	2.304881e+01	2.310298e+01	2.315703e+01	2.321094e+01	2.326473e+01	↳
↳2.331840e+01	2.337195e+01	2.342537e+01	2.347867e+01	2.353185e+01	2.358491e+01	↳
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↳2.457129e+01	2.462211e+01	2.467282e+01	2.472343e+01	2.477394e+01	2.482434e+01	↳
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↳2.633910e+01	2.638652e+01	2.643385e+01	2.648109e+01	2.652826e+01	2.657533e+01	↳
↳2.662233e+01	2.666924e+01	2.671607e+01	2.676282e+01	2.680948e+01	2.685607e+01	↳
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↳2.772631e+01	2.777136e+01	2.781633e+01	2.786124e+01	2.790607e+01	2.795082e+01	↳
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↳2.826214e+01	2.830633e+01	2.835046e+01	2.839452e+01	2.843850e+01	2.848243e+01	↳
↳2.852628e+01	2.857006e+01	2.861378e+01	2.865743e+01	2.870102e+01	2.874454e+01	↳
↳2.878799e+01	2.883138e+01	2.887471e+01	2.891796e+01	2.896116e+01	2.900429e+01	↳
↳2.904735e+01	2.909035e+01	2.913329e+01	2.917617e+01	2.921898e+01	2.926173e+01	↳
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↳2.95924e+01	2.960150e+01	2.964370e+01	2.968583e+01	2.972791e+01	2.976993e+01	↳
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↳3.055730e+01	3.059818e+01	3.063901e+01	3.067978e+01	3.072049e+01	3.076116e+01	↳
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↳3.104430e+01	3.108454e+01	3.112473e+01	3.116486e+01	3.120495e+01	3.124498e+01	↳
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↳3.152378e+01	3.156341e+01	3.160299e+01	3.164252e+01	3.168200e+01	3.172143e+01	↳
↳3.176081e+01	3.180014e+01	3.183942e+01	3.187866e+01	3.191785e+01	3.195698e+01	↳
↳3.199608e+01	3.203512e+01	3.207412e+01	3.211306e+01	3.215197e+01	3.219082e+01	↳
↳3.222963e+01	3.226839e+01	3.230710e+01	3.234577e+01	3.238439e+01	3.242297e+01	↳
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↳3.269173e+01	3.272994e+01	3.276811e+01	3.280623e+01	3.284431e+01	3.288235e+01	↳
↳3.292034e+01	3.295829e+01	3.299620e+01	3.303406e+01	3.307188e+01	3.310965e+01	↳
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↳3.337288e+01	3.341031e+01	3.344770e+01	3.348506e+01	3.352237e+01	3.355963e+01	↳
↳3.359686e+01	3.363404e+01	3.367119e+01	3.370829e+01	3.374535e+01	3.378238e+01	↳
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↳3.404040e+01	3.407710e+01	3.411377e+01	3.415039e+01	3.418697e+01	3.422352e+01	↳
↳3.426002e+01	3.429649e+01	3.433291e+01	3.436930e+01	3.440565e+01	3.444197e+01	↳

↳3.447824e+01	3.451448e+01	3.455067e+01	3.458683e+01	3.462296e+01	3.465904e+01	↵
↳3.469509e+01	3.473110e+01	3.476707e+01	3.480300e+01	3.483890e+01	3.487476e+01	↵
↳3.491059e+01	3.494637e+01	3.498212e+01	3.501784e+01	3.505352e+01	3.508916e+01	↵
↳3.512476e+01	3.516033e+01	3.519587e+01	3.523136e+01	3.526683e+01	3.530225e+01	↵
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↳3.554925e+01	3.558439e+01	3.561950e+01	3.565458e+01	3.568962e+01	3.572463e+01	↵
↳3.575960e+01	3.579454e+01	3.582944e+01	3.586431e+01	3.589915e+01	3.593395e+01	↵
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↳3.617664e+01	3.621117e+01	3.624568e+01	3.628015e+01	3.631459e+01	3.634899e+01	↵
↳3.638336e+01	3.641770e+01	3.645201e+01	3.648629e+01	3.652053e+01	3.655474e+01	↵
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↳3.699661e+01	3.703038e+01	3.706412e+01	3.709783e+01	3.713151e+01	3.716516e+01	↵
↳3.719878e+01	3.723237e+01	3.726592e+01	3.729945e+01	3.733295e+01	3.736642e+01	↵
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↳3.799670e+01	3.802958e+01	3.806244e+01	3.809526e+01	3.812806e+01	3.816083e+01	↵
↳3.819358e+01	3.822629e+01	3.825898e+01	3.829163e+01	3.832426e+01	3.835687e+01	↵
↳3.838944e+01	3.842199e+01	3.845451e+01	3.848700e+01	3.851947e+01	3.855190e+01	↵
↳3.858431e+01	3.861670e+01	3.864905e+01	3.868138e+01	3.871368e+01	3.874596e+01	↵
↳3.877821e+01	3.881043e+01	3.884262e+01	3.887479e+01	3.890693e+01	3.893905e+01	↵
↳3.897113e+01	3.900320e+01	3.903523e+01	3.906724e+01	3.909922e+01	3.913118e+01	↵
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↳3.935415e+01	3.938590e+01	3.941763e+01	3.944933e+01	3.948100e+01	3.951265e+01	↵
↳3.954427e+01	3.957587e+01	3.960744e+01	3.963899e+01	3.967051e+01	3.970201e+01	↵
↳3.973348e+01	3.976492e+01	3.979635e+01	3.982774e+01	3.985912e+01	3.989047e+01	↵
↳3.992179e+01	3.995309e+01	3.998436e+01	4.001561e+01	4.004684e+01	4.007804e+01	↵
↳4.010922e+01	4.014037e+01	4.017150e+01	4.020260e+01	4.023368e+01	4.026474e+01	↵
↳4.029577e+01	4.032678e+01	4.035777e+01	4.038873e+01	4.041966e+01	4.045058e+01	↵
↳4.048147e+01	4.051233e+01	4.054318e+01	4.057400e+01	4.060479e+01	4.063557e+01	↵
↳4.066632e+01	4.069704e+01	4.072775e+01	4.075843e+01	4.078908e+01	4.081972e+01	↵
↳4.085033e+01	4.088092e+01	4.091148e+01	4.094202e+01	4.097254e+01	4.100304e+01	↵
↳4.103351e+01	4.106397e+01	4.109440e+01	4.112480e+01	4.115519e+01	4.118555e+01	↵
↳4.121589e+01	4.124620e+01	4.127650e+01	4.130677e+01	4.133702e+01	4.136725e+01	↵
↳4.139746e+01	4.142764e+01	4.145780e+01	4.148794e+01	4.151806e+01	4.154816e+01	↵
↳4.157823e+01	4.160828e+01	4.163832e+01	4.166833e+01	4.169831e+01	4.172828e+01	↵
↳4.175822e+01	4.178815e+01	4.181805e+01	4.184793e+01	4.187779e+01	4.190763e+01	↵
↳4.193745e+01	4.196724e+01	4.199702e+01	4.202677e+01	4.205650e+01	4.208621e+01	↵
↳4.211590e+01	4.214557e+01	4.217522e+01	4.220485e+01	4.223446e+01	4.226404e+01	↵
↳4.229361e+01	4.232315e+01	4.235268e+01	4.238218e+01	4.241167e+01	4.244113e+01	↵
↳4.247057e+01	4.249999e+01	4.252939e+01	4.255878e+01	4.258814e+01	4.261748e+01	↵
↳4.264680e+01	4.267610e+01	4.270538e+01	4.273464e+01	4.276388e+01	4.279310e+01	↵
↳4.282230e+01	4.285148e+01	4.288064e+01	4.290978e+01	4.293890e+01	4.296800e+01	↵
↳4.299709e+01	4.302615e+01	4.305519e+01	4.308421e+01	4.311322e+01	4.314220e+01	↵
↳4.317116e+01	4.320011e+01	4.322903e+01	4.325794e+01	4.328683e+01	4.331569e+01	↵
↳4.334454e+01	4.337337e+01	4.340218e+01	4.343097e+01	4.345974e+01	4.348850e+01	↵
↳4.351723e+01	4.354595e+01	4.357464e+01	4.360332e+01	4.363198e+01	4.366062e+01	↵
↳4.368924e+01	4.371784e+01	4.374642e+01	4.377499e+01	4.380353e+01	4.383206e+01	↵
↳4.386057e+01	4.388906e+01	4.391753e+01	4.394598e+01	4.397442e+01	4.400283e+01	↵
↳4.403123e+01	4.405961e+01	4.408797e+01	4.411632e+01	4.414464e+01	4.417295e+01	↵
↳4.420124e+01	4.422951e+01	4.425776e+01	4.428600e+01	4.431421e+01	4.434241e+01	↵
↳4.437059e+01	4.439875e+01	4.442690e+01	4.445503e+01	4.448314e+01	4.451123e+01	↵
↳4.453930e+01	4.456736e+01	4.459540e+01	4.462342e+01	4.465142e+01	4.467941e+01	↵
↳4.470738e+01	4.473533e+01	4.476326e+01	4.479118e+01	4.481907e+01	4.484696e+01	↵
↳4.487482e+01	4.490267e+01	4.493050e+01	4.495831e+01	4.498610e+01	4.501388e+01	↵
↳4.504164e+01	4.506938e+01	4.509711e+01	4.512482e+01	4.515251e+01	4.518019e+01	↵
↳4.520785e+01	4.523549e+01	4.526311e+01	4.529072e+01	4.531831e+01	4.534589e+01	↵
↳4.537344e+01	4.540098e+01	4.542851e+01	4.545602e+01	4.548351e+01	4.551098e+01	↵
↳4.553844e+01	4.556588e+01	4.559330e+01	4.562071e+01	4.564810e+01	4.567548e+01	↵
↳4.570284e+01	4.573018e+01	4.575751e+01	4.578482e+01	4.581211e+01	4.583939e+01	↵
↳4.586665e+01	4.589389e+01	4.592112e+01	4.594833e+01	4.597553e+01	4.600271e+01	↵
↳4.602988e+01	4.605702e+01	4.608416e+01	4.611127e+01	4.613837e+01	4.616546e+01	↵
↳4.619253e+01	4.621958e+01	4.624662e+01	4.627364e+01	4.630064e+01	4.632763e+01	↵
↳4.635461e+01	4.638156e+01	4.640851e+01	4.643543e+01	4.646234e+01	4.648924e+01	↵
↳4.651612e+01	4.654299e+01	4.656983e+01	4.659667e+01	4.662349e+01	4.665029e+01	↵
↳4.667708e+01	4.670385e+01	4.673061e+01	4.675735e+01	4.678407e+01	4.681078e+01	↵
↳4.683748e+01	4.686416e+01	4.689082e+01	4.691748e+01	4.694411e+01	4.697073e+01	↵
↳4.699733e+01	4.702392e+01	4.705050e+01	4.707706e+01	4.710360e+01	4.713013e+01	↵

↳4.715665e+01	4.718315e+01	4.720963e+01	4.723610e+01	4.726256e+01	4.728900e+01	↵
↳4.731543e+01	4.734184e+01	4.736823e+01	4.739461e+01	4.742098e+01	4.744733e+01	↵
↳4.747367e+01	4.749999e+01	4.752630e+01	4.755260e+01	4.757888e+01	4.760514e+01	↵
↳4.763139e+01	4.765763e+01	4.768385e+01	4.771006e+01	4.773625e+01	4.776243e+01	↵
↳4.778859e+01	4.781474e+01	4.784088e+01	4.786700e+01	4.789310e+01	4.791920e+01	↵
↳4.794528e+01	4.797134e+01	4.799739e+01	4.802343e+01	4.804945e+01	4.807546e+01	↵
↳4.810145e+01	4.812743e+01	4.815340e+01	4.817935e+01	4.820528e+01	4.823121e+01	↵
↳4.825712e+01	4.828301e+01	4.830890e+01	4.833476e+01	4.836062e+01	4.838646e+01	↵
↳4.841229e+01	4.843810e+01	4.846390e+01	4.848968e+01	4.851546e+01	4.854121e+01	↵
↳4.856696e+01	4.859269e+01	4.861841e+01	4.864411e+01	4.866980e+01	4.869548e+01	↵
↳4.872114e+01	4.874679e+01	4.877243e+01	4.879805e+01	4.882366e+01	4.884925e+01	↵
↳4.887484e+01	4.890040e+01	4.892596e+01	4.895150e+01	4.897703e+01	4.900255e+01	↵
↳4.902805e+01	4.905354e+01	4.907901e+01	4.910448e+01	4.912992e+01	4.915536e+01	↵
↳4.918078e+01	4.920619e+01	4.923159e+01	4.925697e+01	4.928234e+01	4.930770e+01	↵
↳4.933305e+01	4.935838e+01	4.938370e+01	4.940900e+01	4.943429e+01	4.945957e+01	↵
↳4.948484e+01	4.951010e+01	4.953534e+01	4.956056e+01	4.958578e+01	4.961098e+01	↵
↳4.963617e+01	4.966135e+01	4.968651e+01	4.971166e+01	4.973680e+01	4.976193e+01	↵
↳4.978704e+01	4.981214e+01	4.983723e+01	4.986231e+01	];		