

Global Air Pollution Exposure and Benefits of Emissions Reductions for Global Health

L. A. Parsons^{1*}, D. Shindell¹, G. Faluvegi^{2,3}, E. Nagamoto¹

¹ Nicholas School of the Environment, Duke University, Durham, NC 27708

² Center for Climate Systems Research, Columbia University, New York, NY 10025

³ NASA Goddard Institute for Space Studies, New York, NY 10025

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Introduction

Supplementary figures and tables. **Figure S1** shows global maps illustrating annual mean (2015-2019) ambient PM_{2.5} in CMIP6 models and observations. **Figure S2** shows global maps illustrating the difference in annual mean (2015-2019) ambient PM_{2.5} in CMIP6 models and observations. **Figure S3** shows maps of grid level cumulative avoided premature mortality (2015-2099) associated with ambient PM_{2.5} exposure in CMIP6 models. **Figure S4** shows maps of country-level avoided population-weighted PM_{2.5} exposure in CMIP6 models in 2050-2054. **Table S1** lists CMIP6 models with data available to calculate ambient PM_{2.5} in SSP1-2.6 and SSP3-7.0. **Table S2** compares estimates of the fraction of global population exposed to PM_{2.5} concentration thresholds after observations are regridded to various spatial grid resolutions (~5km, ~30km, ~55km). **Table S3** lists country-level, cumulative (2015-2099) avoided premature deaths per million people under SSP1-2.6 vs SSP3-7.0.

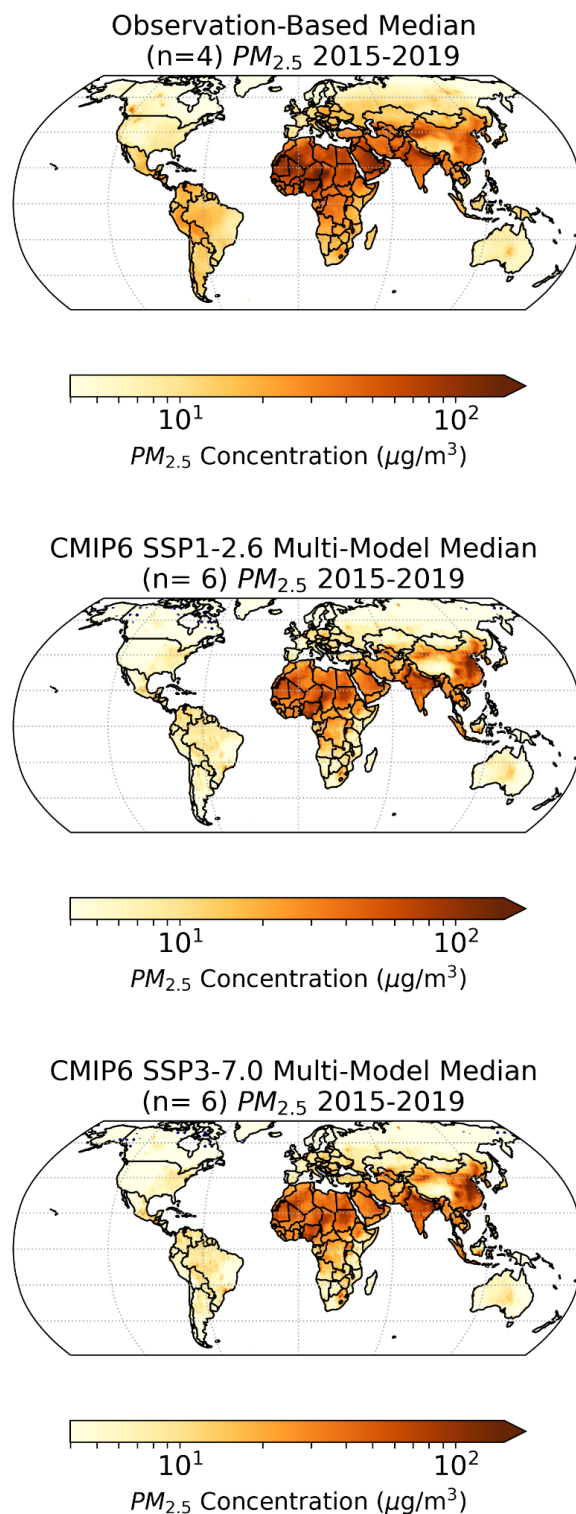
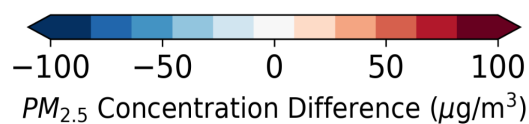
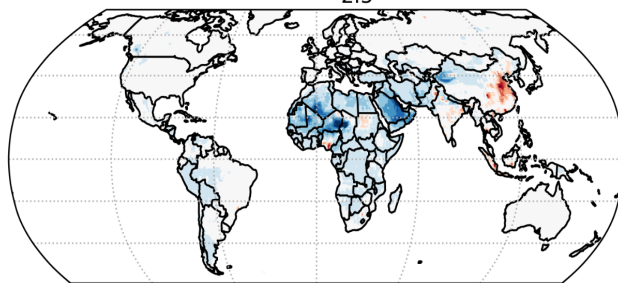


Figure S1. Average near-surface $PM_{2.5}$ in the four observation-based datasets used in the main text (top), CMIP6 multi-model median SSP1-2.6 (center), and CMIP6 multi-model median SSP3-7.0 (bottom) in the 2015-2019 time period.

CMIP6 SSP1-2.6 Multi-Model Median - Observation Mean
Difference in $PM_{2.5}$ 2015-2019



CMIP6 SSP3-7.0 Multi-Model Median - Observation Mean
Difference in $PM_{2.5}$ 2015-2019

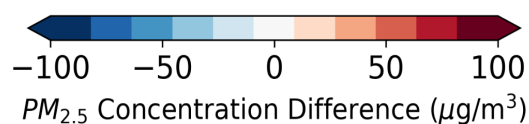
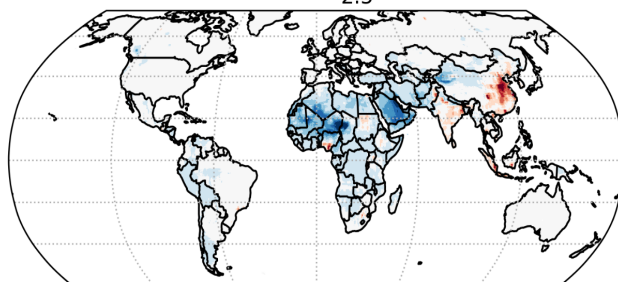


Figure S2. CMIP6 multi-model median SSP1-2.6 difference from observation-based mean near-surface $PM_{2.5}$ (top), and CMIP6 multi-model median SSP3-7.0 difference from observation-based mean near-surface $PM_{2.5}$ (bottom) in the 2015-2019 time period.

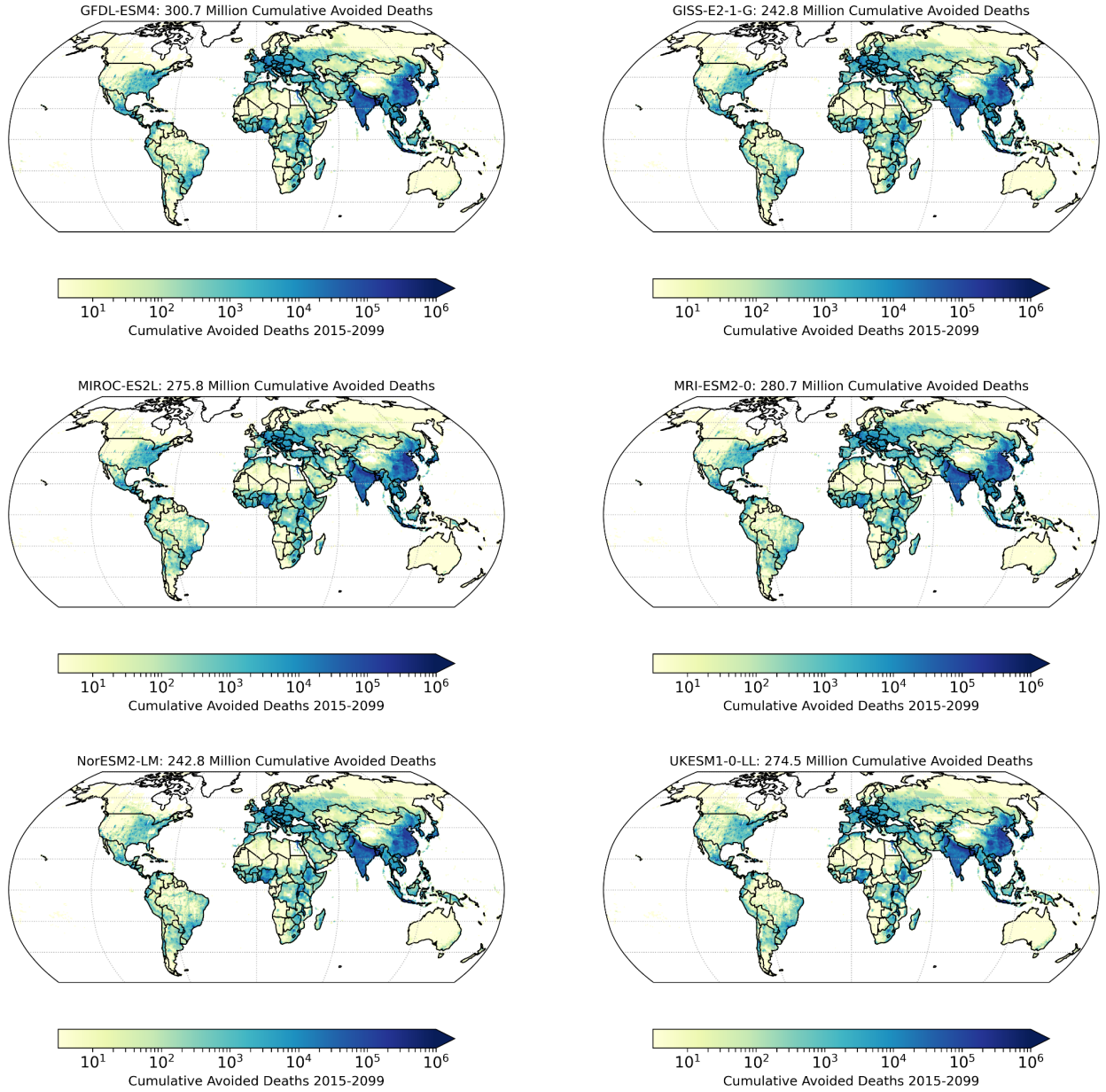


Figure S3. Cumulative avoided premature mortality associated with ambient PM_{2.5} exposure in Coupled Model Intercomparison Project, Phase 6 (CMIP6) simulations. Avoided premature deaths are calculated from the difference in cumulative (2015-2099) premature deaths in CMIP6 low (SSP1-2.6) vs high (SSP3-7.0) emissions scenarios. Population is fixed at 2015 levels for all calculations.

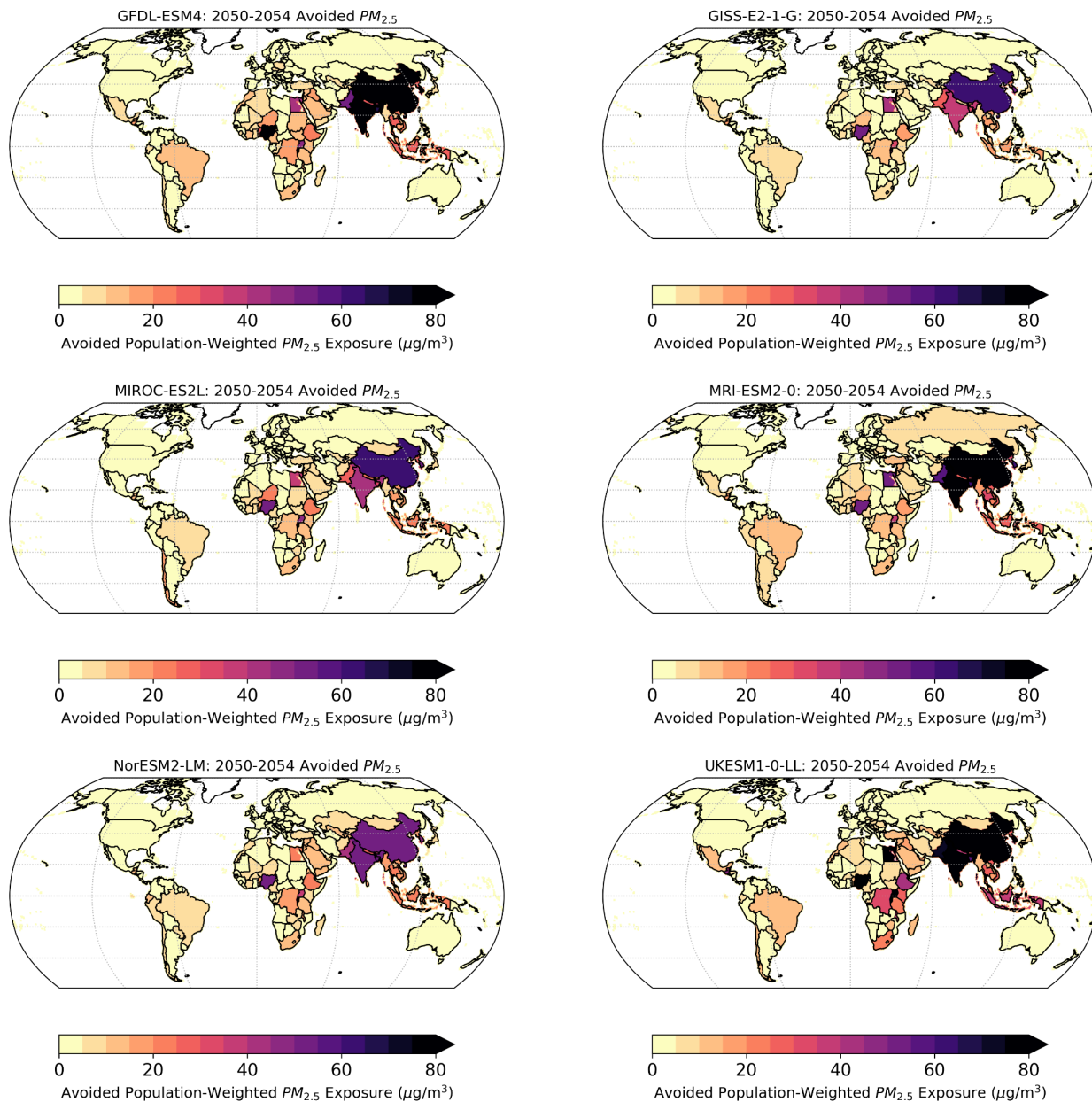


Figure S4. Country-level avoided population-weighted $PM_{2.5}$ exposure in Coupled Model Intercomparison Project, Phase 6 (CMIP6) simulations 2050-2054. Avoided population-weighted $PM_{2.5}$ exposure is calculated from the difference in country-level, population-weighted $PM_{2.5}$ in CMIP6 low (SSP1-2.6) vs high (SSP3-7.0) emissions scenarios. Population is fixed at 2015 levels for all calculations.

Table S1. CMIP6 models with data available to calculate near-surface, annual mean ambient PM_{2.5} in the SSP1-2.6 and SSP3-7.0 experiments.

CMIP6 Model	Ensemble Member
GFDL-ESM4	r1i1p1f1
GISS-E2-1-G	r1i1p3f1
MIROC-ES2L	r1i1p1f2
MRI-ESM2-0	r1i1p1f1
NorESM2-LM	r1i1p1f1
UKESM1-0-LL	r1i1p1f2

Table S2. Global fraction of population exposed to PM_{2.5} concentration thresholds in the four observation datasets used in the main text after observations were interpolated to spatial resolutions of ~5km (~0.05° x ~0.05°), ~30km (~0.3° x ~0.3°), and ~55km (~0.5° x ~0.5°). Top section shows results for data interpolated to a ~5km spatial resolution, center section shows results for ~30km spatial resolution, and bottom shows results for ~55km spatial resolution.

Observation Dataset	~5km GPWV4 gridded data		
	5µg m-3	10µg m-3	35µg m-3
MERRA-2	0.991	0.835	0.314
Shaddick	0.911	0.866	0.546
GBD2019	0.976	0.897	0.492
Van Donkelaar	0.960	0.884	0.414
	~30km GPWV4 gridded data		
	5µg m-3	10µg m-3	35µg m-3
MERRA-2	0.991	0.836	0.320
Shaddick	0.910	0.864	0.548
GBD2019	0.961	0.883	0.490
Van Donkelaar	0.948	0.874	0.413
	~55km GPWV4 gridded data		
	5µg m-3	10µg m-3	35µg m-3
MERRA-2	0.991	0.835	0.315
Shaddick	0.880	0.832	0.529
GBD2019	0.928	0.848	0.478
Van Donkelaar	0.910	0.835	0.394

Table S3. Country-level, cumulative (2015-2099) avoided premature deaths per million people associated with annual mean ambient PM_{2.5} exposure in the SSP1.26 vs SSP3-7.0 scenarios. Individual CMIP6 model results shown in center columns, and CMIP6 multi-model median avoided cumulative premature deaths shown in the right column. Values of zero indicate no information for that country.

Country	GFDL-ESM4	GISS-E2-1-G	MIROC-ES2L	MRI-ESM2-0	NorESM2-LM	UKESM1-0-LL	CMIP6 Median
Afghanistan	10221.9	6306.0	8343.3	11975.6	13940.4	12791.9	10596.736
Albania	14652.8	10849.2	16165.2	16097.3	13974.2	17291.6	15096.975
Algeria	7662.0	4931.5	8201.9	6613.9	5777.7	10802.4	6823.053
Andorra	11022.9	9713.3	1244.4	12488.9	10467.5	12286.6	10745.215
Angola	983.5	307.2	353.4	-360.0	-432.4	-2250.0	-27.235
Antigua+Barbuda	1615.7	228.1	60.8	1960.8	1252.0	200.8	740.063
Argentina	14720.1	18990.1	19804.6	17751.9	19288.6	22165.3	18895.532
Armenia	26869.6	17431.5	31003.3	24467.1	26573.4	28173.2	26370.711
Australia	8542.4	7812.4	1783.2	9748.6	8753.6	10753.4	8357.102
Austria	33170.0	27065.8	25108.9	28902.7	23430.2	31791.0	28040.22
Azerbaijan	18522.8	13791.0	17800.9	22605.8	17119.1	18147.3	17624.759
Bahamas	3196.7	1519.7	3504.7	4881.5	1218.9	2603.0	2880.432
Bahrain	7539.4	4592.8	6592.6	5537.2	8670.6	8394.8	7066.029
Bangladesh	35628.8	29770.2	30013.0	39359.1	34278.6	34273.6	34273.198
Barbados	2320.8	86.9	-821.1	3106.2	1591.7	722.0	1156.818
Belarus	37779.9	30690.6	29706.3	38080.3	28449.8	32222.1	32462.117
Belgium	40186.3	30602.6	26925.0	35358.2	29241.9	36342.2	32681.47
Belize	1996.1	1621.6	4338.2	4558.2	1988.2	3688.7	2396.127
Benin	15437.4	6481.2	16178.9	11002.5	12528.7	7974.5	11938.669
Bhutan	31461.7	22598.5	24974.9	35882.3	30334.3	27056.0	29667.083
Bolivia	8185.1	10213.6	12068.0	9273.1	9799.1	9899.9	9883.369
Bosnia+Herzegovina	40371.3	26952.7	28534.3	36528.3	29588.1	39715.0	34626.286
Botswana	2734.4	6174.3	5834.8	4073.5	7284.4	2678.6	4682.412
Brazil	23343.2	18882.7	18610.6	23841.3	16256.4	23343.0	20452.454
Brunei Darussalam	17600.6	14166.0	9982.0	16337.2	12965.9	14945.4	14458.04
Bulgaria	43799.4	33715.3	55156.3	43667.3	34799.0	41671.8	41845.48
Burkina Faso	4809.4	5152.3	7689.3	6461.0	6816.4	4775.7	6067.697
Burundi	43821.2	41884.5	32931.3	40771.1	39863.8	48883.1	41369.68
Cambodia	23469.3	20701.6	20132.8	27320.7	21459.5	18790.7	22028.414
Cameroon	8667.5	10647.2	10566.3	8143.7	6390.4	5996.8	8580.125
Canada	16550.6	19203.2	16695.8	19169.5	16706.5	24171.6	18879.973
Cape Verde	1082.2	152.2	-604.8	1330.6	1409.2	-781.2	553.926
Central African Rep.	4695.7	5033.6	8527.8	5131.2	3869.7	-2402.7	4771.93

Chad	1108.9	4484.6	4017.9	4543.5	5209.7	-3524.6	3835.501
Chile	21081.6	18211.1	22527.3	23617.7	19838.2	32875.2	21877.722
China	83535.7	69242.5	77840.9	70526.7	60665.7	75328.8	73273.917
Colombia	5860.2	5409.2	8091.6	7180.1	6048.9	7343.6	6558.21
Comoros	1610.9	1195.5	0.0	2247.7	1830.2	1420.5	1529.892
Congo	7865.2	6439.9	6495.1	6101.6	4396.5	7226.4	6375.93
Cook Islands	2199.4	220.9	0.0	0.0	2492.2	1081.4	651.189
Costa Rica	5898.5	2236.5	7174.8	5838.2	4728.2	4023.4	5211.644
Croatia	37729.9	26625.4	25908.0	35179.2	29494.7	33831.9	32060.134
Cuba	7653.1	3766.2	9535.0	12100.7	5035.1	6756.7	7114.69
Cyprus	8043.6	10355.0	20516.9	12994.8	13105.3	11492.2	11932.121
Czech Republic	43289.9	32452.0	31659.6	35268.7	28322.6	39970.1	34578.959
Cote d'Ivoire	10682.1	7504.9	10429.0	9526.3	7754.1	3644.0	8390.643
Dem.Peo.Rep.of Korea	67865.4	58482.6	73250.0	69690.5	49780.1	55031.2	63591.673
Dem.Rep.of the Congo	15167.3	14186.1	13451.4	13242.5	13322.3	16993.5	14032.985
Denmark	16982.0	11207.3	3840.1	10207.5	12700.0	12897.2	11883.033
Djibouti	5189.8	5011.6	6152.8	6041.8	9855.3	7140.0	6308.546
Dominica	2152.3	652.9	453.5	2507.1	1614.4	934.3	1274.344
Dominican Republic	7852.9	7460.8	5054.2	8254.7	5749.6	7569.6	7197.597
Ecuador	16121.6	10481.8	14968.0	15897.7	17704.7	17465.1	15303.519
Egypt	38179.2	44628.1	52168.4	34773.3	42729.9	39011.0	41097.978
El Salvador	9336.1	8895.2	15498.9	18922.1	11040.6	12533.8	12746.542
Equatorial Guinea	1636.9	-300.4	2057.2	-1159.4	-2985.2	-1405.5	-697.78
Eritrea	7051.0	4836.9	5653.0	6091.5	9347.4	9357.3	6992.1
Estonia	16576.6	25628.0	8530.9	19963.4	23509.3	24512.7	21304.282
Ethiopia	18190.0	16967.9	19903.0	14636.6	18161.8	26604.7	18208.049
Fiji	4266.0	528.3	0.0	-257.7	1447.6	388.8	397.589
Finland	7301.2	16192.7	2366.5	9130.9	9656.8	10555.0	9056.046
France	22691.4	15794.6	5837.6	19194.6	16653.1	20453.3	17937.93
Gabon	3131.3	1607.9	1238.0	607.5	-1739.7	968.9	1039.769
Gambia	2543.3	6240.4	4539.3	6953.1	6760.8	5578.0	6001.64
Georgia	38199.5	23051.4	46302.9	37726.5	34588.1	26469.4	35262.605
Germany	39750.5	31458.8	24804.8	34315.8	28288.2	35347.5	32710.092
Ghana	8519.6	5081.1	7558.3	8445.0	7037.7	-201.3	6870.001
Greece	17834.7	13391.6	22529.2	20144.1	16382.9	18616.1	18031.802
Grenada	2212.0	335.1	77.7	2656.8	1233.3	794.8	1014.049
Guatemala	19538.1	18898.7	15911.2	16880.9	11369.6	23739.8	17877.911
Guinea	4885.9	4843.6	5482.6	6266.3	4643.0	1102.3	5011.597
Guinea-Bissau	-2017.2	4679.2	4688.7	5514.2	6736.3	3549.1	4814.311
Guyana	4769.0	3150.4	1500.2	4495.4	3873.0	1397.7	3409.981

Haiti	13066.4	9575.2	16287.1	11237.5	7553.0	14510.0	11170.479
Honduras	4778.8	5511.5	7911.4	5753.8	3334.1	6032.8	5673.499
Hungary	44432.1	32591.4	39672.7	38640.0	29956.9	40525.2	37482.848
Iceland	1078.8	-175.8	0.1	1.8	384.1	656.1	147.325
India	54676.2	39870.8	49057.8	53365.1	48310.9	44919.1	49325.25
Indonesia	45507.4	36954.1	40290.8	40276.1	36057.8	48922.5	40792.057
Isl.Rep.of Iran	9130.9	6532.9	7461.0	8511.4	9475.5	10810.3	8606.128
Iraq	6908.3	5035.0	6090.4	6064.7	5283.4	7604.4	6027.987
Ireland	9879.0	1222.0	0.0	231.9	3642.2	4023.3	2307.073
Israel	22654.5	21029.3	29144.7	25020.6	25548.9	25042.9	24569.657
Italy	25624.1	21369.7	12401.0	26320.8	22125.7	25846.4	23378.868
Jamaica	7378.3	5160.8	12504.6	9830.8	6481.2	7450.8	7432.208
Japan	45049.5	35535.5	45930.8	48204.7	37841.3	38132.9	41272.424
Jordan	9874.8	7630.3	11430.9	9790.6	10317.2	11393.8	10186.676
Kazakhstan	14445.3	12132.7	15239.8	21167.2	14337.5	14392.6	15069.132
Kenya	14318.9	14755.7	13052.0	12709.9	11195.2	20973.0	13495.819
Kiribati	4232.3	166.4	0.0	75.3	8174.8	524.2	400.744
Kuwait	6684.2	4241.3	5045.0	4452.9	6038.0	7646.8	5655.905
Kyrgyzstan	10745.9	8638.0	15038.3	12451.1	16344.1	18541.7	13088.251
Lao Peo.Dem.Rep.	22111.9	18977.3	20012.7	27716.5	19973.2	15278.5	19999.254
Latvia	20390.3	30424.1	9372.3	24586.6	29670.6	25595.5	25050.816
Lebanon	21493.2	19826.1	24429.2	25832.7	22126.2	20941.7	21868.873
Lesotho	18943.1	18236.7	23009.3	16839.8	18278.9	21442.8	18920.26
Liberia	4347.0	2529.3	4800.6	3277.0	-185.0	-431.2	2934.708
Libyan Arab Jamahiriya	6207.8	4215.9	6062.0	2515.8	4424.4	4305.0	4341.229
Lithuania	27193.3	30419.5	14252.4	27813.8	29050.0	29726.3	28124.384
Luxembourg	30183.5	23540.9	8814.9	23053.2	20505.8	26814.9	23247.035
Madagascar	16104.0	13163.9	12239.1	14049.8	12183.5	16501.5	14121.321
Malawi	20037.0	18473.3	19471.2	18600.0	18267.5	28542.2	19288.171
Malaysia	28251.0	23180.1	26072.4	27727.1	20289.1	28659.5	25382.137
Maldives	5437.2	4087.1	5686.0	7535.6	5157.6	5441.5	5401.312
Mali	2272.3	2852.3	4353.6	3656.8	4036.3	3046.2	3349.198
Malta	8074.1	6217.7	13352.2	9321.6	5965.2	7415.9	7719.872
Marshall Islands	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Mauritania	-457.0	1128.6	1888.2	1612.6	4737.5	404.9	1337.102
Mauritius	2321.1	239.7	0.7	1387.7	1620.7	119.4	835.304
Mexico	19557.2	17076.5	16527.7	21298.2	11221.8	19396.8	17939.452
Fed.Sts.of Micronesia	1293.0	2047.8	0.0	-68.2	800.4	1121.6	903.365
Monaco	18315.5	14244.9	2469.4	19564.5	14533.6	17465.9	15999.752
Mongolia	20250.6	17232.1	23021.4	19554.0	22462.5	27551.4	21061.035

Morocco+W.Sahara	15917.4	12239.5	16449.5	16046.9	14254.6	24175.1	15320.898
Mozambique	5137.6	6447.4	6728.0	5205.0	4325.0	3500.5	5007.93
Myanmar	24071.1	24269.3	25059.9	32795.4	26186.3	21678.2	24972.208
Namibia	-113.3	331.1	914.8	-189.0	3013.6	-921.8	193.396
Nauru	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Nepal	18306.1	10293.1	23088.0	24439.4	20095.5	22155.6	19244.301
Netherlands	28690.8	21406.0	19004.1	23668.9	21643.8	23224.6	22675.233
New Zealand	2679.0	661.9	0.0	2.4	3098.6	756.1	595.911
Nicaragua	5156.4	4586.7	6313.2	5471.2	4993.8	5522.7	5271.126
Niger	4190.1	4779.9	10279.3	4990.1	4685.8	696.1	4720.566
Nigeria	21561.7	21441.9	25269.8	21016.6	21079.3	19690.1	21537.083
Niue	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Norway	683.2	5398.5	2.1	519.9	1515.9	5499.9	1141.048
Oman	5663.6	3614.5	4895.5	2008.1	7021.7	6181.8	5275.765
Pakistan	39206.3	26329.3	31480.8	42934.7	41981.4	40417.2	37519.458
Palau	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Panama	6343.6	3115.6	6375.4	8298.2	4549.9	5750.3	5800.406
Papua New Guinea	9249.1	9415.3	4743.4	8729.7	14172.8	12495.9	9957.713
Paraguay	13608.3	15305.8	13349.8	12553.2	13292.6	12872.0	13459.062
Peru	8195.2	8110.7	8367.0	14097.8	9373.4	12658.8	9647.155
Philippines	15404.5	12674.3	14642.3	17212.3	11302.1	17620.8	15081.512
Poland	38451.1	29452.9	28311.2	31983.3	26424.8	32532.9	31499.182
Portugal	17632.0	12057.8	7248.8	20567.6	17268.6	27414.0	17059.837
Qatar	4679.8	2748.7	3891.6	3567.7	4210.4	6617.2	4053.028
Rep.of Korea	73378.5	58192.9	69090.6	65014.1	51994.2	67047.6	65383.005
Rep.of Moldova	33190.5	23142.5	36130.7	31419.2	24184.0	24120.3	28574.588
Romania	43724.2	33286.3	45913.6	41193.1	32898.8	39815.6	39978.735
Russian Fed.	37530.4	28988.4	34485.1	38924.8	28246.9	26655.7	32033.711
Rwanda	39705.7	34489.1	32455.6	33054.0	32074.4	40826.9	34218.604
St.Kitts+Nevis	0.0	0.0	0.0	0.0	0.0	0.0	0.0
St.Lucia	1837.3	359.0	119.2	2234.0	1203.1	789.9	996.494
St.Vincent+Grenadines	2315.8	507.9	220.9	2753.4	1454.4	966.1	1210.244
Samoa	1877.7	261.5	0.0	-870.8	-105.0	590.8	130.74
San Marino	25973.2	20352.9	8669.4	25015.8	20680.1	24995.6	22999.005
Sao Tome+Principe	2314.1	915.3	574.1	974.4	-2323.1	-41.7	722.196
Saudi Arabia	6913.8	3645.3	4718.4	4826.3	9562.8	7458.2	5991.237
Senegal	-337.9	1742.1	1753.3	2690.0	3886.6	797.2	1800.057
Serbia+Montenegro	50518.7	37700.6	52754.1	48237.8	39980.5	56231.3	47576.797
Seychelles	4612.8	1849.6	0.0	7021.5	4326.4	4354.3	4340.363
Sierra Leone	4652.7	3912.0	4035.4	5142.1	2830.3	1994.0	3979.313

Singapore	49957.7	37859.0	42937.6	53805.7	45426.9	44626.7	45078.0
Slovakia	38093.6	28041.6	30131.0	31924.0	24445.4	34163.9	30851.731
Slovenia	30494.2	23338.7	17097.4	28178.2	24547.9	27581.0	26052.409
Solomon Islands	2006.6	1952.8	16.1	49.7	2712.5	626.9	1200.381
Somalia	804.3	3192.1	4295.7	6589.3	5816.6	3947.9	4356.157
South Africa	16277.0	14099.6	16599.3	15384.7	14860.1	19796.3	15983.802
Spain	13666.4	10370.0	8236.1	15587.0	12679.1	14877.8	13029.75
Sri Lanka	29155.5	21171.2	28387.8	34014.4	25655.2	27497.3	27114.586
Sudan	5628.6	5331.4	6056.4	5052.4	5228.1	3564.5	5494.723
Suriname	4070.9	4577.5	3744.1	4751.6	7946.5	2069.9	4255.258
Swaziland	8103.3	10002.8	11012.5	6790.5	4131.9	7894.5	7851.19
Sweden	6374.7	12758.6	668.2	5634.3	8656.4	7451.6	6421.007
Switzerland	29474.6	23712.7	21697.8	23849.5	21283.0	27593.2	24222.003
Syrian Arab Rep.	13975.8	12202.7	16011.6	15062.6	15040.6	17749.8	14835.967
Tajikistan	11796.5	9967.3	11954.0	15905.9	16521.4	18974.4	13800.367
Thailand	35581.0	29353.5	29964.1	40164.9	27252.4	30915.5	31327.726
Fmr.Yugoslav Rep.of Macedonia	27157.1	18119.2	30559.5	27263.4	21349.0	31944.0	27086.81
Timor-Leste	3251.6	2902.3	586.9	4427.5	3446.5	4398.0	3379.25
Togo	10390.9	5373.5	14941.1	10234.6	11733.8	268.1	10044.925
Tonga	1857.7	22.9	0.0	121.8	-250.6	28.2	15.036
Trinidad+Tobago	3268.0	1730.2	400.1	4804.9	2765.0	2130.4	2452.306
Tunisia	11273.1	8705.0	16213.5	10526.7	9762.3	14089.4	10920.117
Turkey	17325.5	14127.0	22693.6	17628.1	15784.3	20100.1	17562.79
Turkmenistan	3375.2	5122.2	-989.7	9210.1	5309.4	2627.8	4529.725
Tuvalu	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Uganda	25474.7	24484.6	26371.0	22064.7	22106.3	26657.8	24578.614
Ukraine	41116.0	26606.3	39063.2	41667.3	28000.4	27815.8	33040.202
United Arab Emirates	8218.1	4938.4	5647.5	2944.6	8707.2	11040.2	7006.002
United Kingdom	18630.1	9329.9	609.6	10187.2	12552.0	14544.3	11656.945
United Rep.of Tanzania	14084.2	14677.9	13618.7	12651.2	11329.9	15742.4	13343.065
United Sts.of America	19706.2	18935.6	19711.3	20027.6	12561.8	16665.8	18770.775
Uruguay	19331.3	18859.6	9624.1	20128.8	20660.8	24198.1	19609.758
Uzbekistan	15518.3	14145.2	14800.2	20361.3	21431.9	24055.8	17762.082
Vanuatu	2149.5	361.6	0.0	-164.8	640.1	-324.2	182.812
Boliv.Rep.of Venezuela	6748.7	4500.9	11259.9	8233.9	6061.8	7478.1	7175.511
Viet Nam	39654.8	32047.1	34054.8	41543.0	28342.1	38932.9	35329.777
Yemen	6984.8	4155.7	5285.1	6894.1	10055.6	9502.8	7102.974
Zambia	5991.2	7300.8	7289.6	5715.2	11313.5	7462.4	6877.574
Zimbabwe	14938.3	18803.3	18684.8	14833.1	17185.1	19255.8	16610.161