Climate Change Around the World

Per Krusell
Institute for International Economic Studies, NBER, CEPR

Joint with Anthony A. Smith, Jr.
Yale University, NBER

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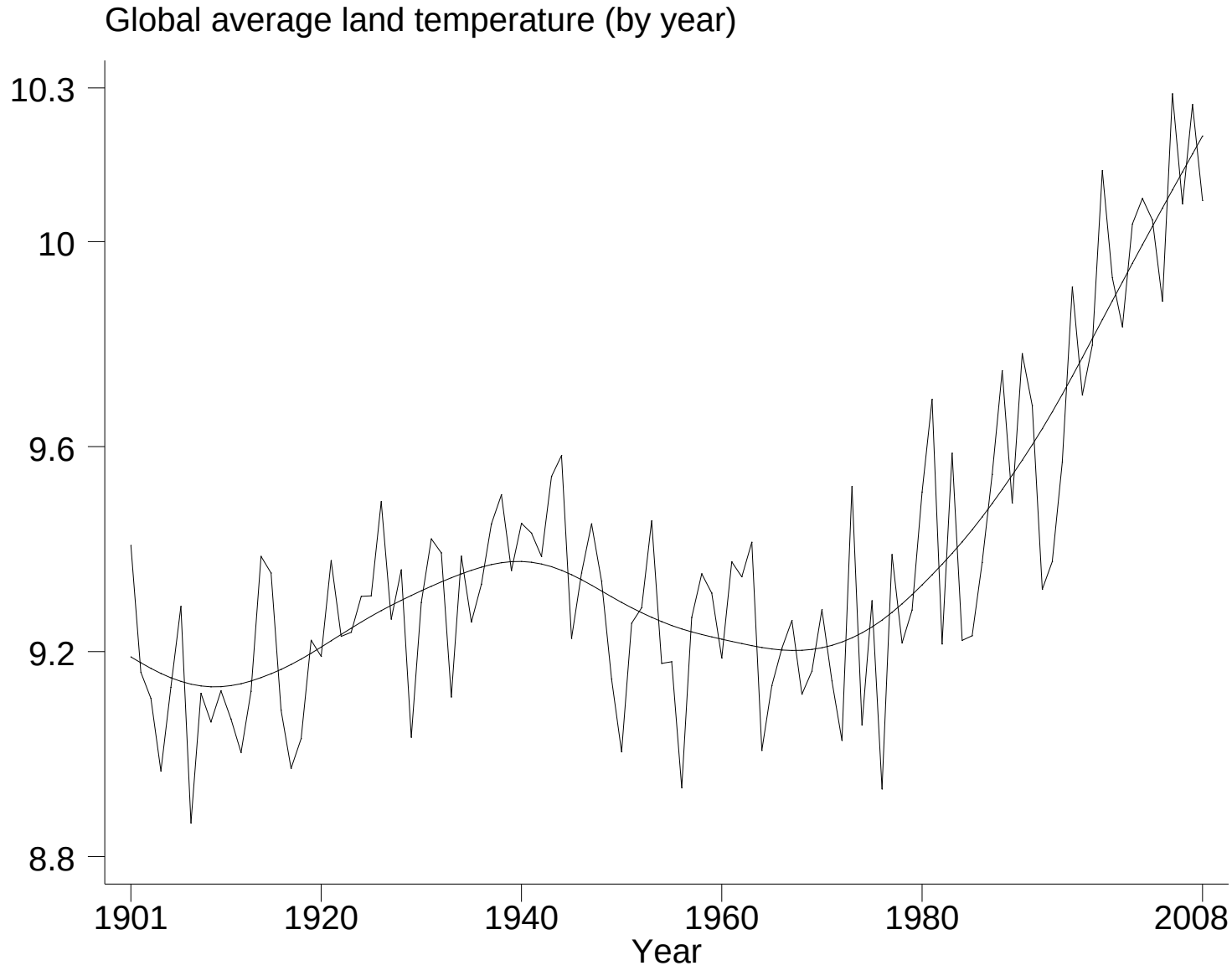
The project

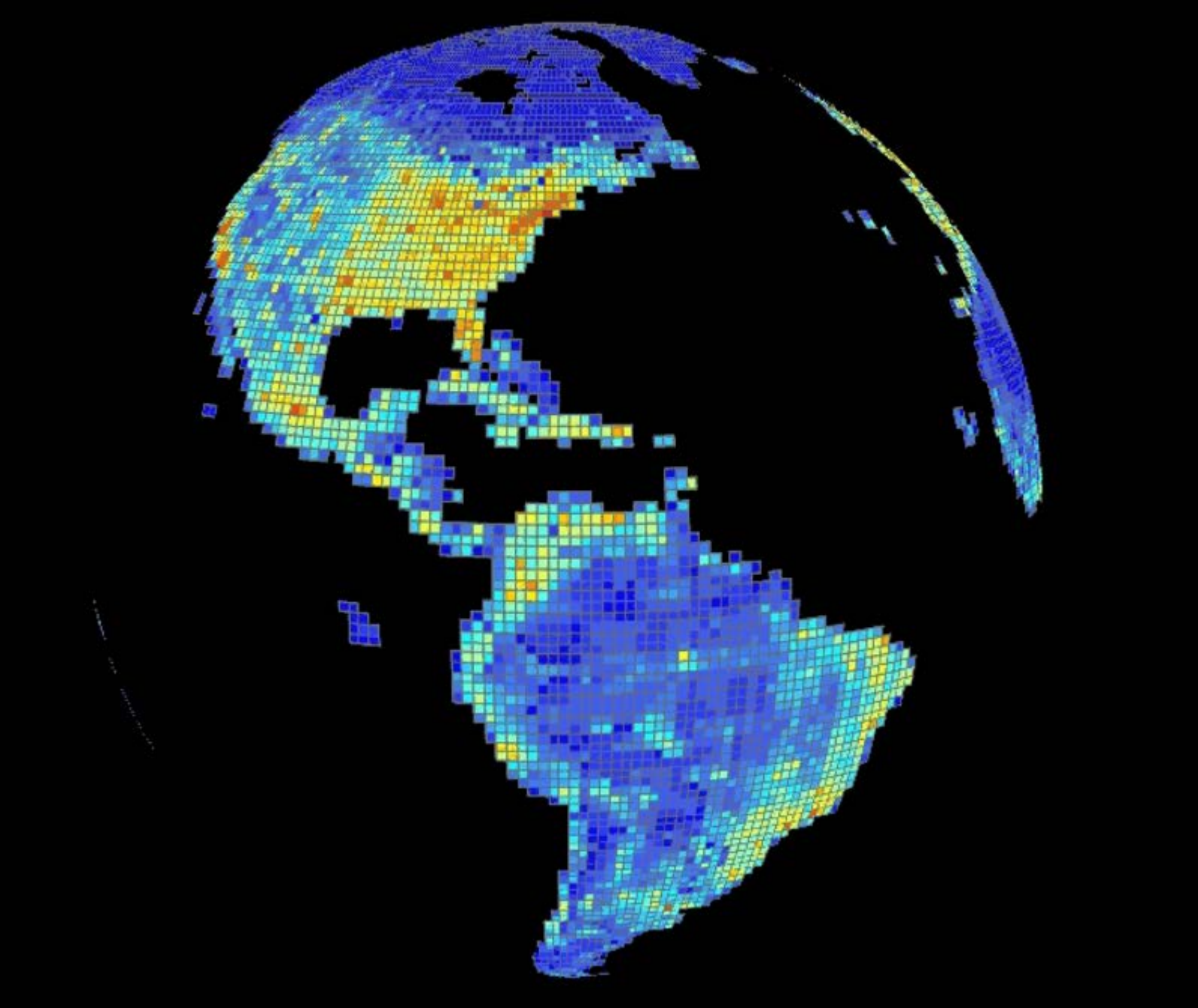
- Construct global model of economy-climate interactions featuring a high degree of geographic resolution ($1^\circ \times 1^\circ$ regions).
- Use the model as a laboratory to quantify the distributional effects of climate change and climate policy.
- If a set of regions imposes a carbon tax (or a quantity restriction on emissions), how does the path of global emissions respond? Which regions gain and which lose, and by how much?

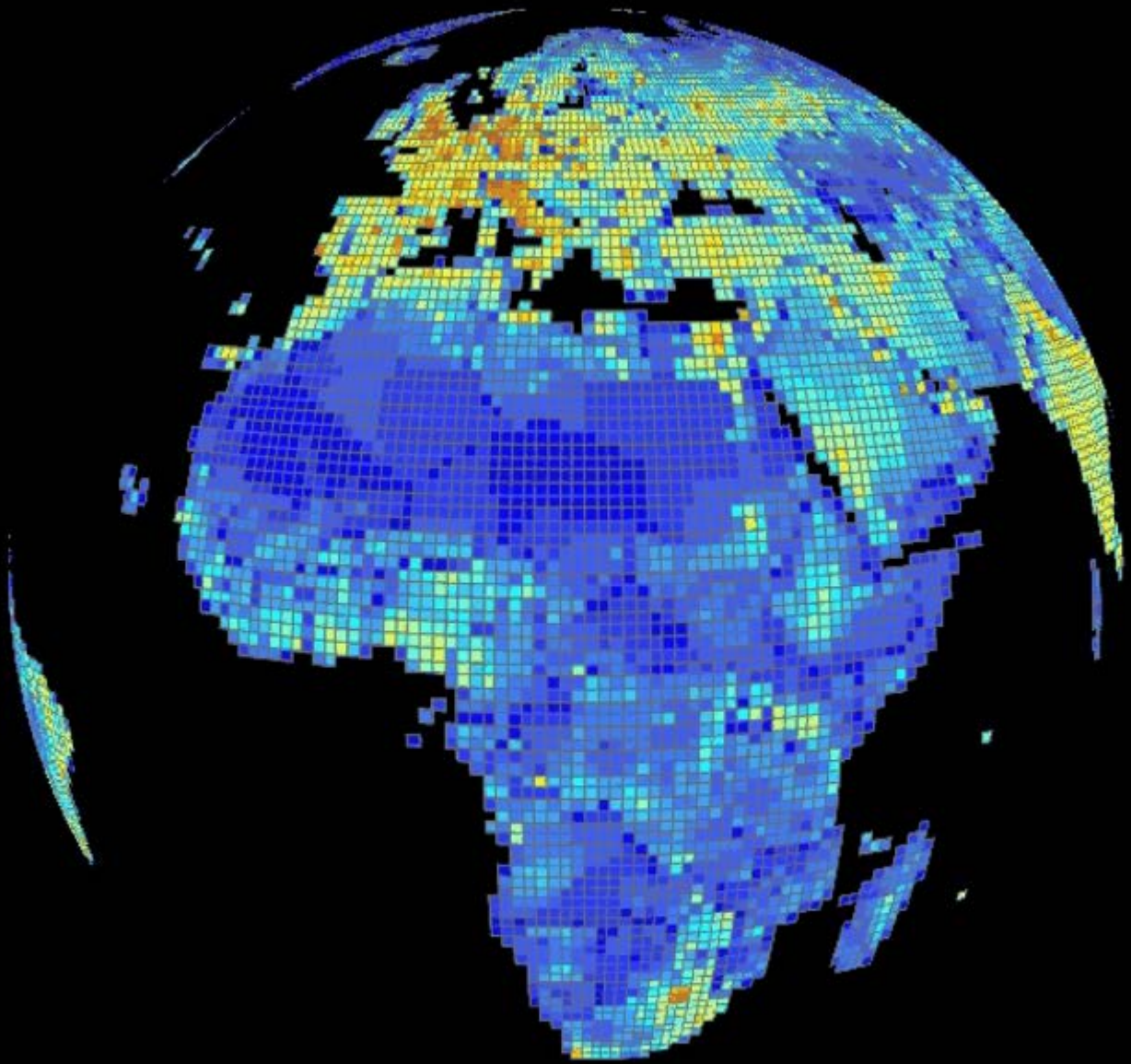
The data

- Unit of analysis: $1^\circ \times 1^\circ$ cells containing land.
- The model contains $\sim 19,000$ regions (or cell-countries).
- Nordhaus's G-Econ database: gross domestic product (GDP) and population for all such cells in 1990, 1995, 2000, and 2005.
- Matsuura and Willmott: gridded ($0.5^\circ \times 0.5^\circ$) monthly terrestrial temperature data for 1900–2008.

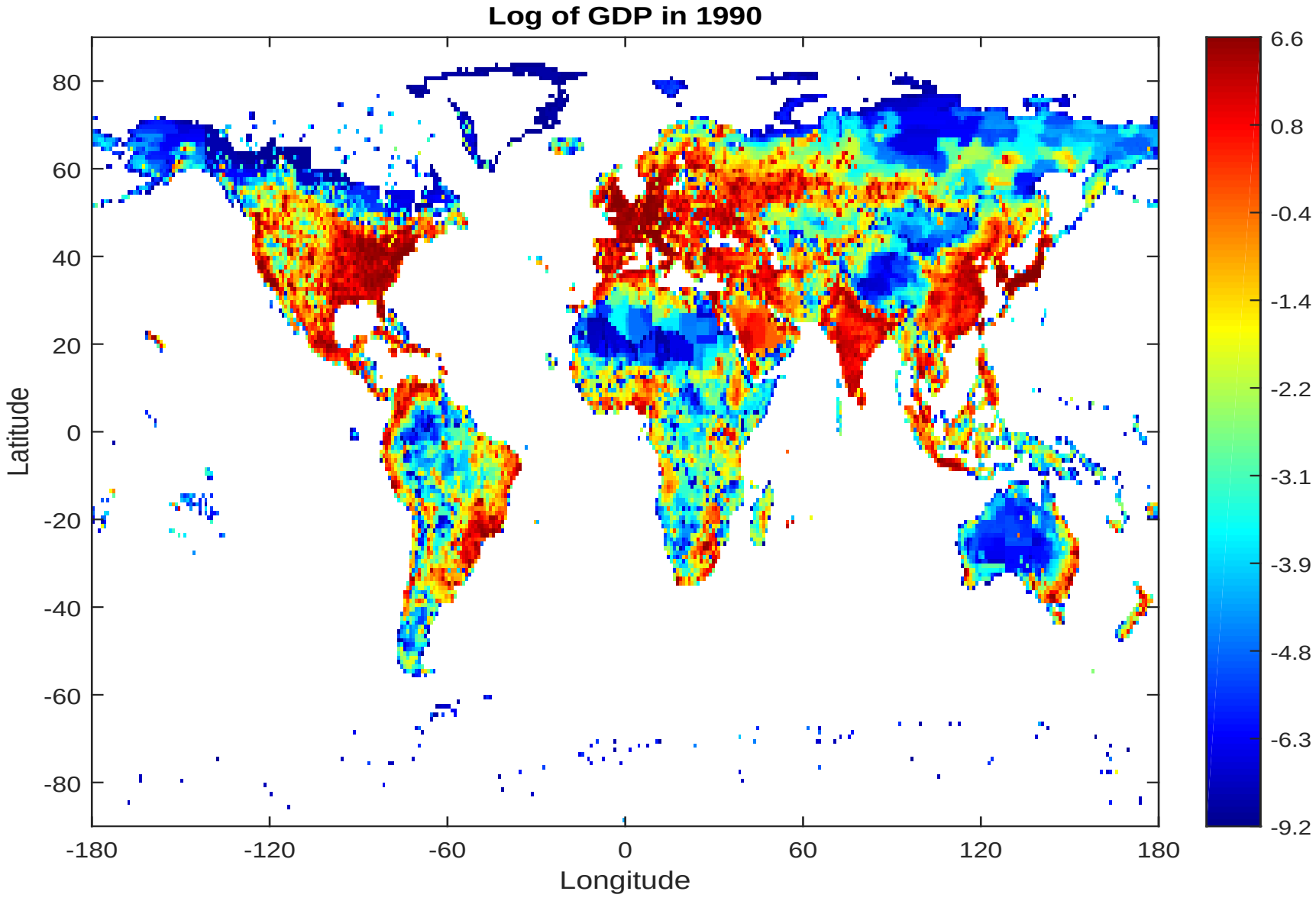

Global average land temperature (by year)
10.3
10
9.6
9.2
8.8
1901
1920
1940
1960
1980
2008
Year

Nordhaus's G-Econ globe with output by regions

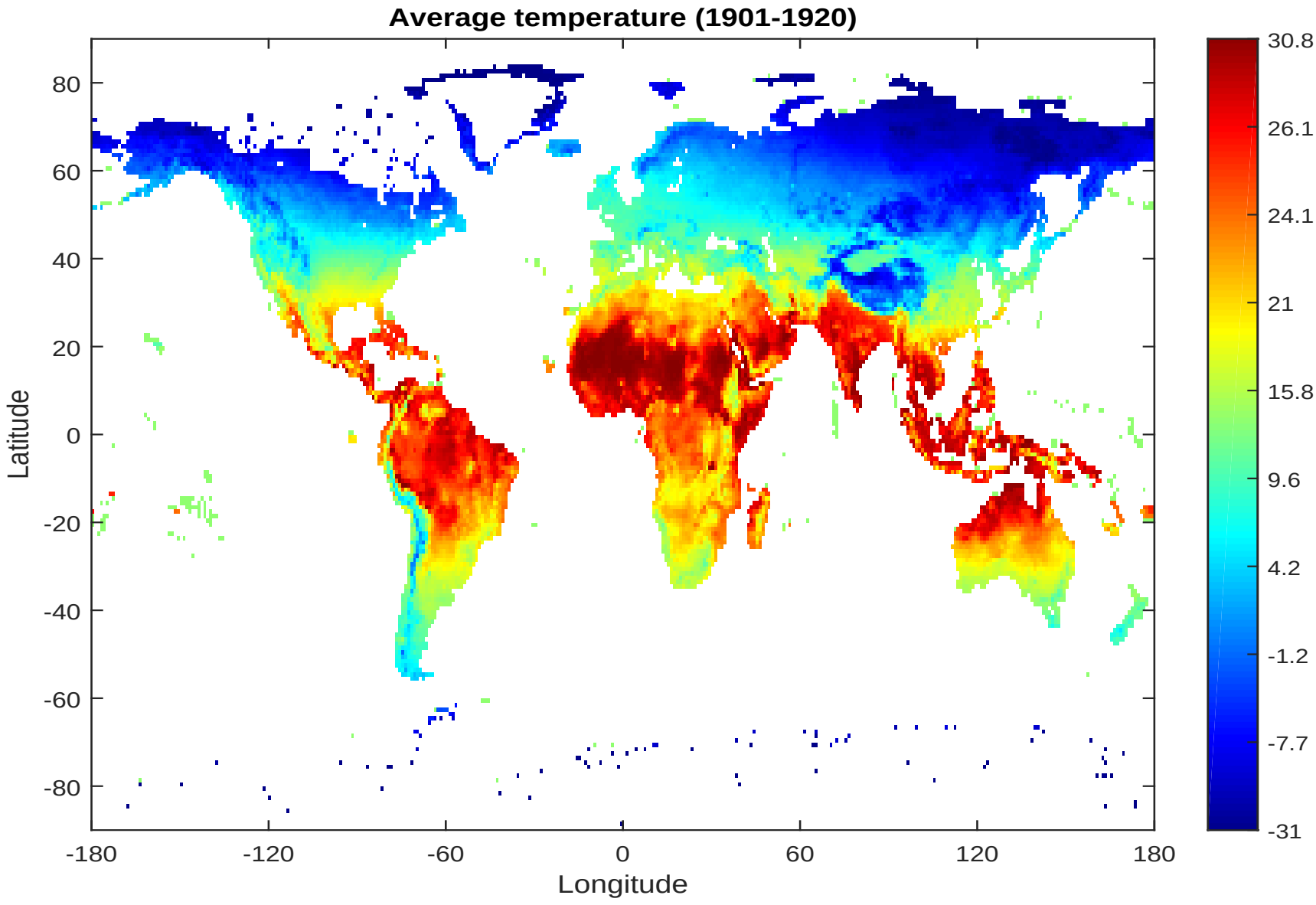




same data on our map


Log of GDP in 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6.6
0.8
-0.4
-1.4
-2.2
-3.1
-3.9
-4.8
-6.3
-9.2

temperature map of the world


Average temperature (1901-1920)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
30.8
26.1
24.1
21
15.8
9.6
4.2
-1.2
-7.7
-31

Natural-science background I: the climate

Climate summarized by average global temperature T: departure from preindustrial level. The logic behind role of humans:

- Greenhouse gases (e.g., CO_2) in atmosphere: let sunlight through but hinder outgoing heat radiation from earth.
- So add $CO_2 \Rightarrow$ "more heat stays". Effect on T?

1. How much less energy out: Arrhenius, 1896. $F = \frac{\eta}{\ln 2} \ln\left(\frac{S}{\bar{S}}\right)$;
   - F: "forcing", reduced energy out
   - S: current CO_2 concentration, $\bar{S}$: initial level
   - in atmosphere now: $S = 840\text{GtC}$; preindustrial: $\bar{S} = 600\text{GtC}$.
2. Energy budget: energy in $>$ energy out $\Rightarrow$ earth heats.
   - $\frac{dT}{dt} = \sigma(F - \kappa T)$; hotter planet emits "feedback" heat $-\kappa T$.
   - Preindustrial period: $F = 0$, $T = 0$; after that, rise in F.
   - New equilibrium: $T_\infty = F/\kappa$.

$\Rightarrow T_\infty = \frac{\lambda}{\ln 2} \ln\left(\frac{S}{\bar{S}}\right)$; $\lambda \equiv \eta/\kappa$, called "climate sensitivity".
Significant uncertainty: $\lambda \approx 3^\circ\text{C} \pm 1.5^\circ\text{C}$.

Natural-science background II: the carbon cycle

Carbon cycle: how emissions of CO_2 enter/exit atmosphere. Key:

- emissions spread globally very quickly ("global externality")
- depreciation structure:
  - smooth, but very slow; some stays "forever" in atmosphere
  - nonlinear (and feedback from higher temperature) but linear approximation not so bad.

Numbers:

- emissions: 10GtC/year (recall $S = 840$Gtc)
- $\Delta S_t \approx 4.5$GtC/year
- estimated remaining carbon: oil+gas 300GtC, coal much bigger ($>$ 3,000GtC? Rogner, 1997);
- hence coal is key!

To summarize: emissions $\rightarrow$ carbon in atmosphere $\rightarrow$ forcing $\rightarrow$ temperature.

Bad if externality negative: if higher T causes "damages".

Integrated assessment models

Pioneered by Nordhaus (DICE, RICE). Quantitative theory, computational.

Key components:

- climate system (as above)
- carbon cycle (as above)
- economic model of emissions AND damages

Economic model: needs to be dynamic, forward-looking, possibly allowing stochastics (temperature variations, disasters).

Here:

- climate system more elaborate
- economic model and damages new.

Some relevant background from past work

Model development:

- a number of our earlier papers on this can be viewed as "pilot studies" for present work
- in particular, Golosov, Hassler, K, and Tsyvinski (GHKT; *Econometrica*, 2014) develops simple one-sector DSGE setting.

Build present structure on earlier insights: one-region version of present model very close to GHKT.

Overview for remainder of talk

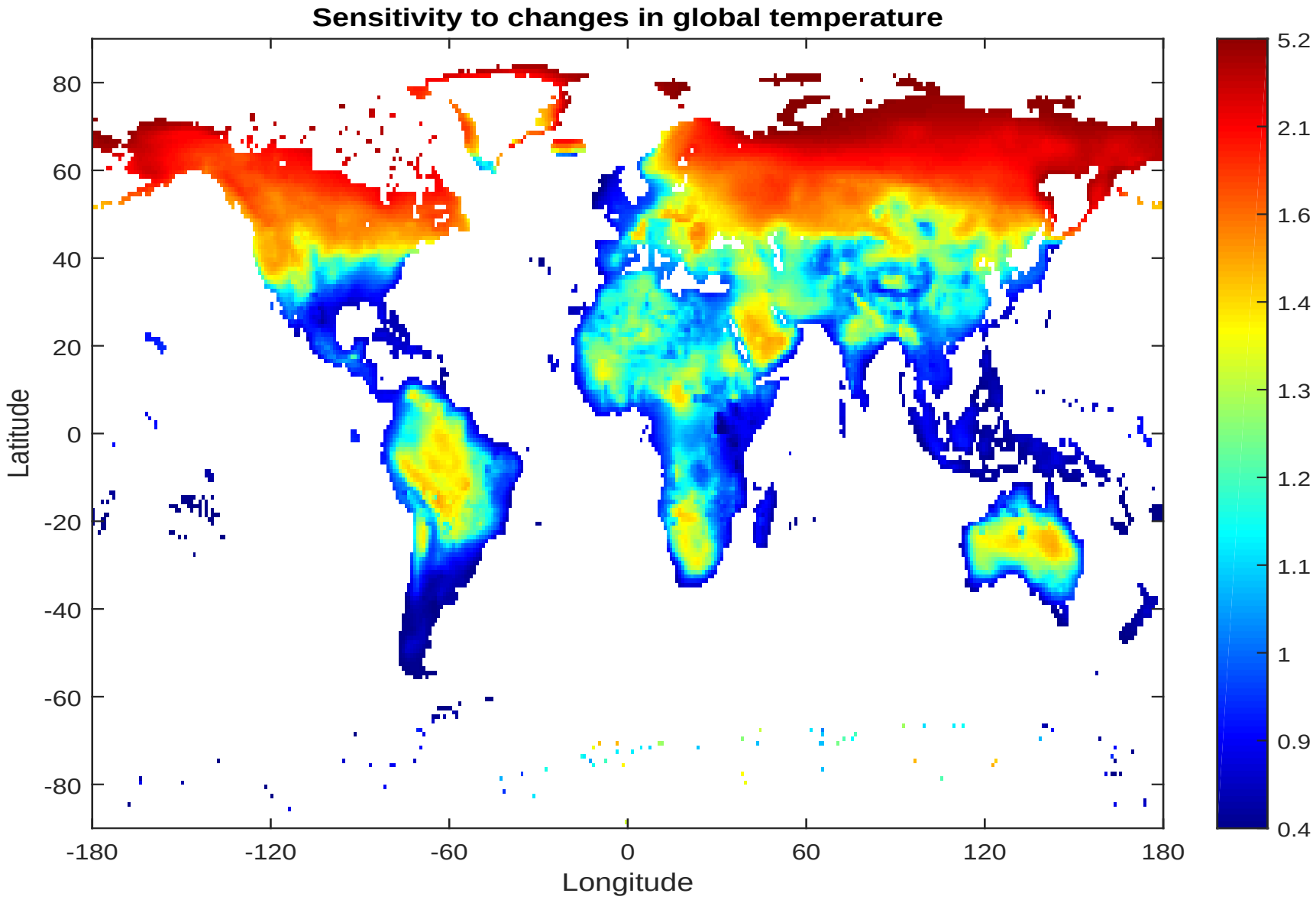
1. our climate modeling
2. our damage specification
3. economic model
4. calibration, computation
5. results
6. conclusions, future

Our climate modeling

How will region ℓ's climate respond to global warming?

- Answer given by complex global and regional climate models. But not feasible to combine these with economic model.
- Therefore, use "pattern scaling": statistical description of temperature in a given region as a function of a single state variable—average global temperature.
- Capture sensitivity of temperature in region ℓ to global temperature T in a coefficent (linear structure; standard).
- With help of climate scientists, use runs of (highly) complex climate models into the future to estimate sensitivities.

global map with estimated sensitivities: how much temperature goes up everywhere if T rises by one degree

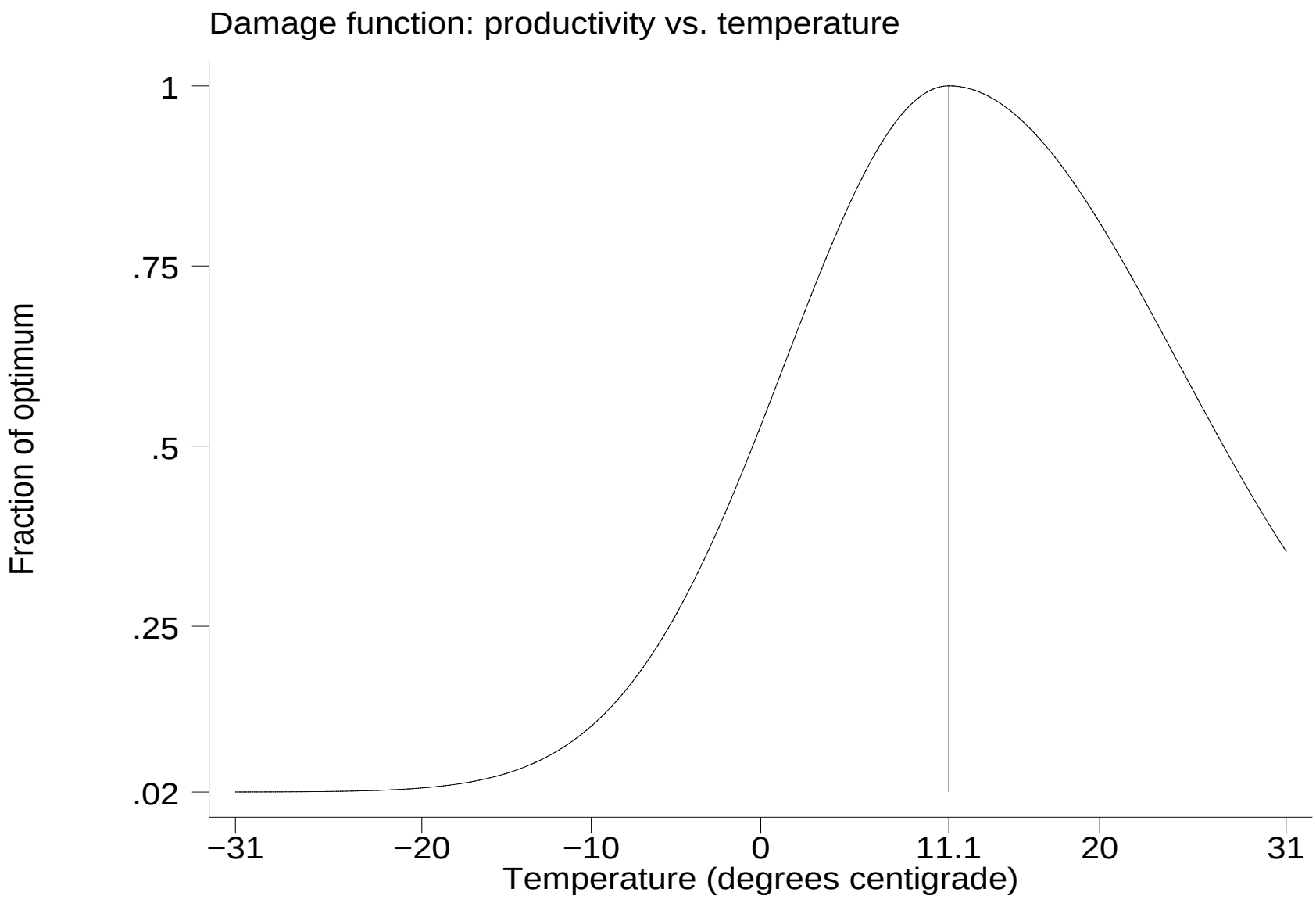

Sensitivity to changes in global temperature
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
5.2
2.1
1.6
1.4
1.3
1.2
1.1
1
0.9
0.4

Our damage specification

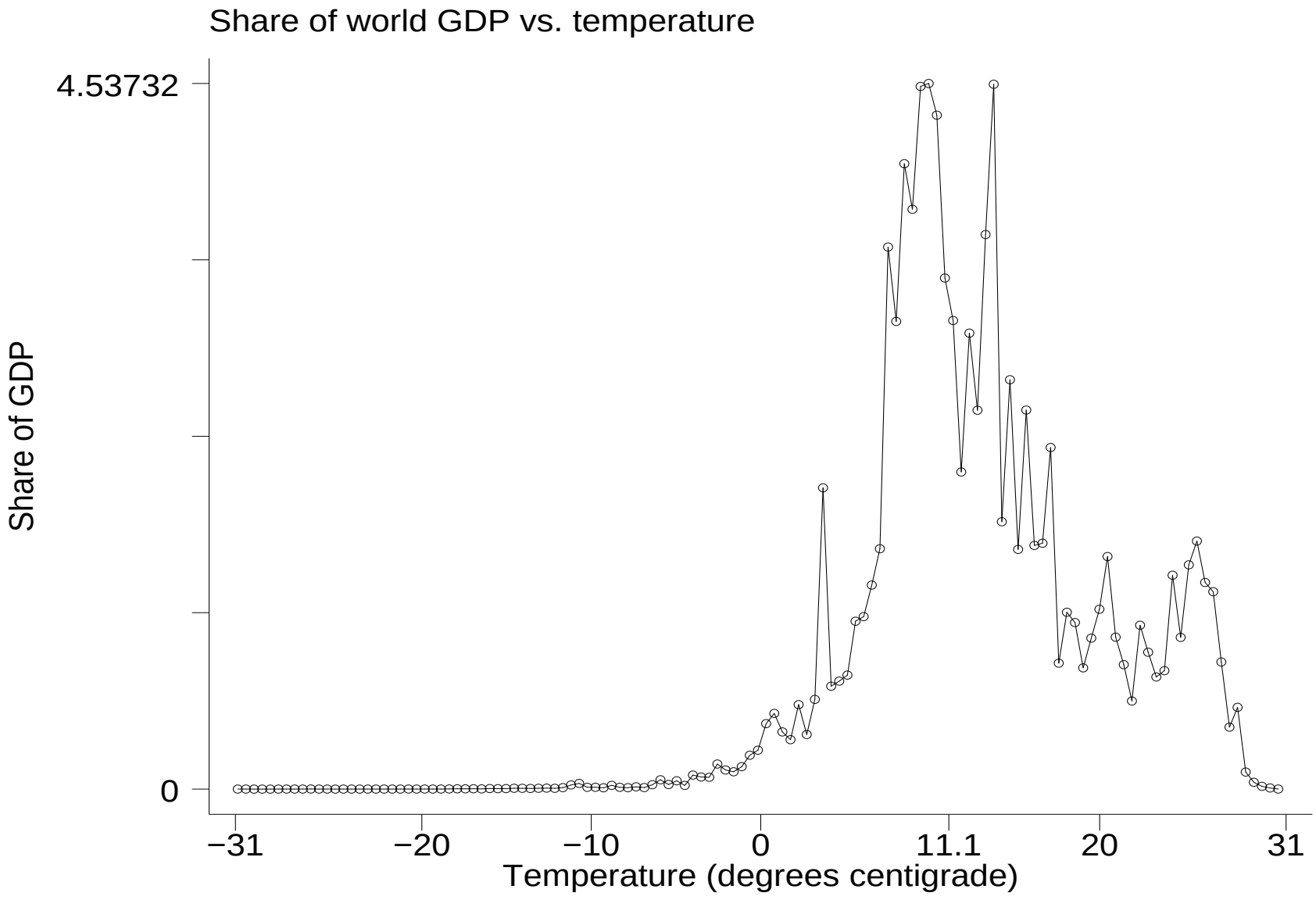
What are the damages in region ℓ as a result of global warming?

- Damage measurements: overall, weakest part of climate-economy evidence package, particularly for regional assessments.
- Our approach:
  - formulate a damage function *D of local temperature* that is
    - common across all ℓ
    - like Nordhaus's, a TFP drag
    - U-shaped, with three parameters. . .
  - . . . which are estimated to match, when aggregated across all ℓ, the global damages estimated by Nordhaus:
    - Nordhaus's formulation: convex
    - three points used: at 1 degree centigrade, 0.3% output drag; at 2.5, 1.8%; and at 5, 6.8%.
    - Nordhaus's global estimates not much different from those of others (IPCC has recent summary).
- Desmet and Rossi-Hansberg (2014): also a common U-shape, spatial application.

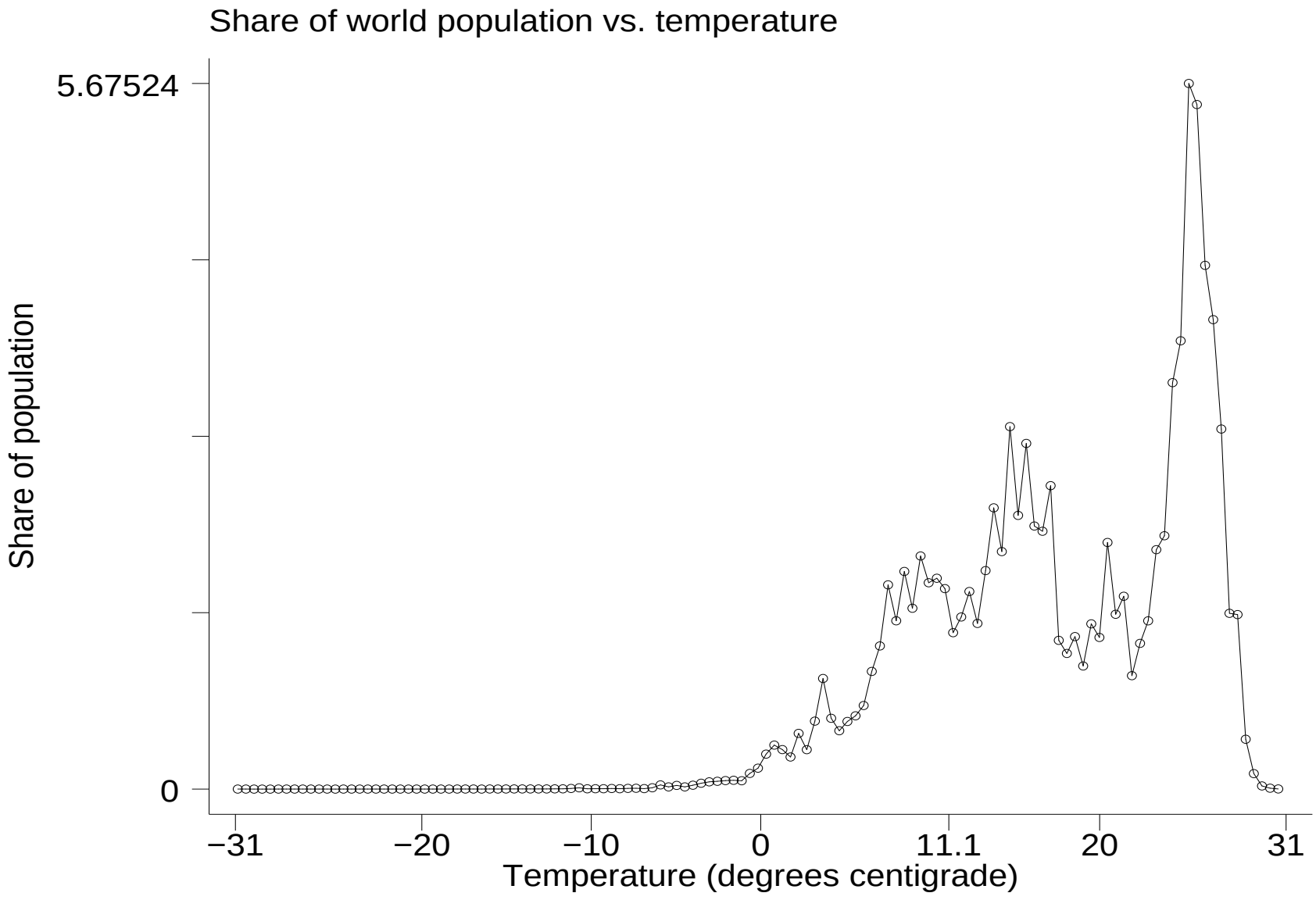
picture of 1 minus estimated U-shaped damage function, as function of local temperature


Damage function: productivity vs. temperature
Fraction of optimum
1
.75
.5
.25
.02
−31
−20
−10
0
11.1
20
31
Temperature (degrees centigrade)

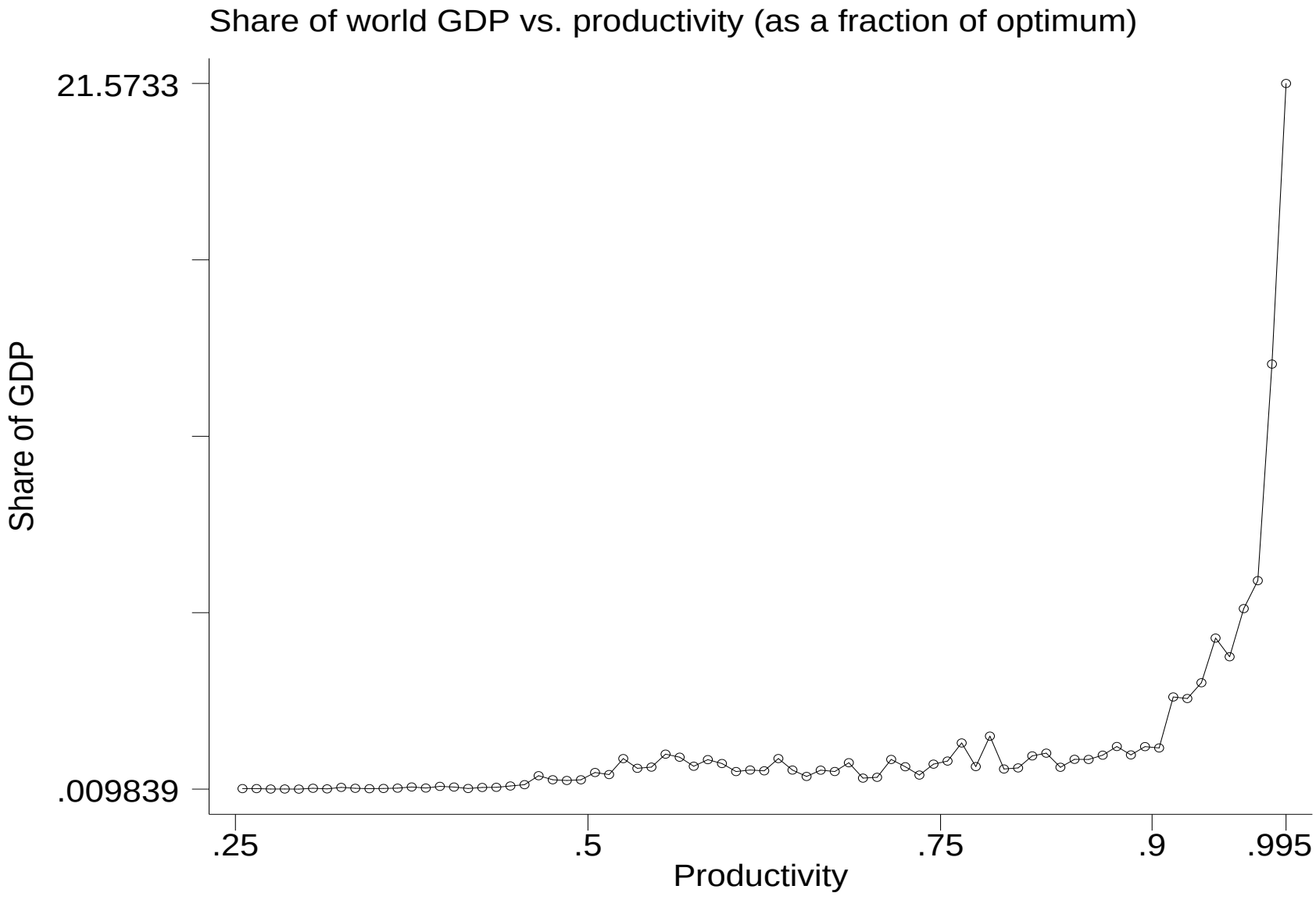
gdp distribution across temperatures (you see that most output is near the optimum)


Share of world GDP vs. temperature
4.53732
0
Share of GDP
−31
−20
−10
0
11.1
20
31
Temperature (degrees centigrade)

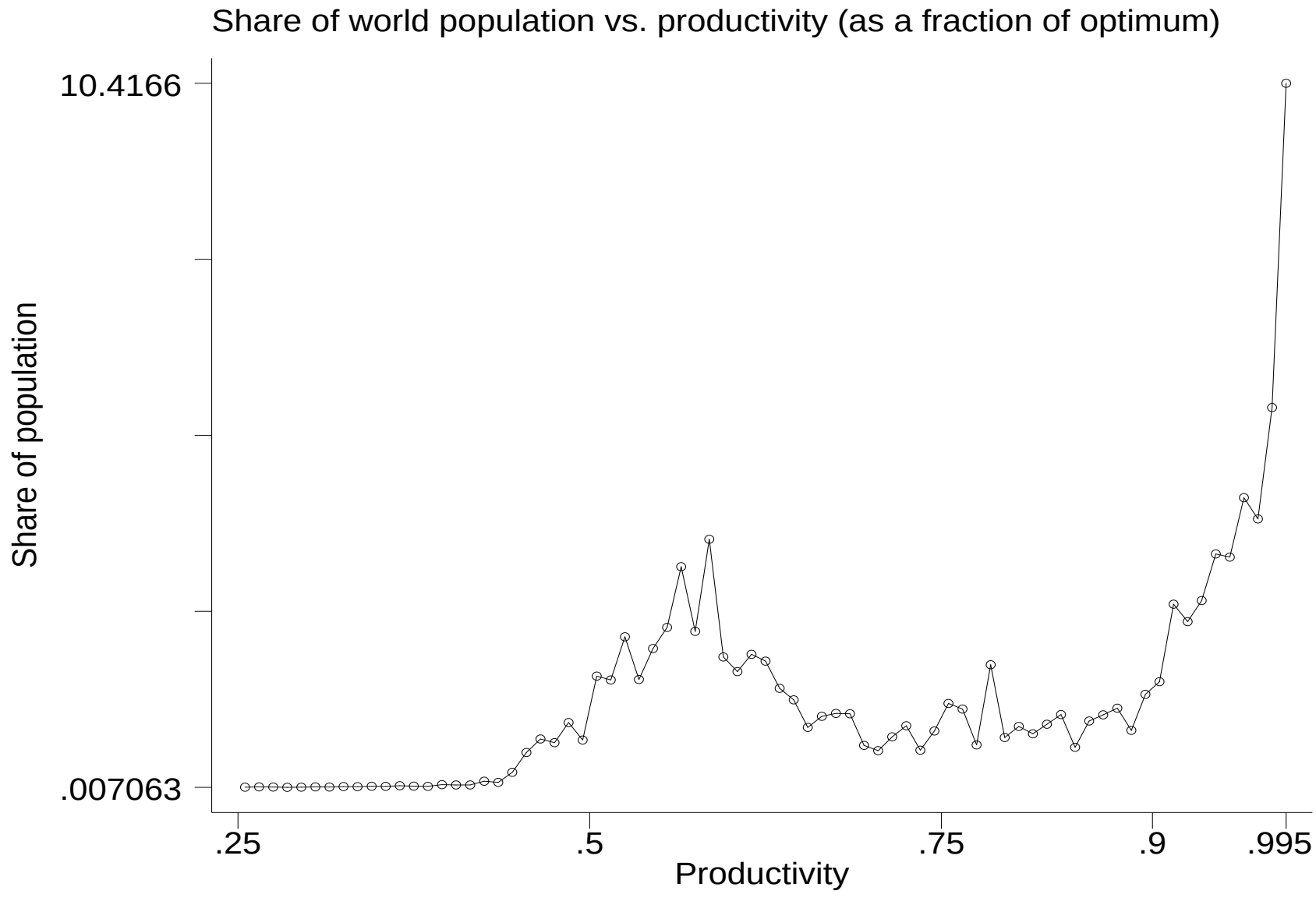
population distribution across temperatures (similar graph, but less concentrated near optimum)


Share of world population vs. temperature
5.67524
0
Share of population
−31
−20
−10
0
11.1
20
31
Temperature (degrees centigrade)

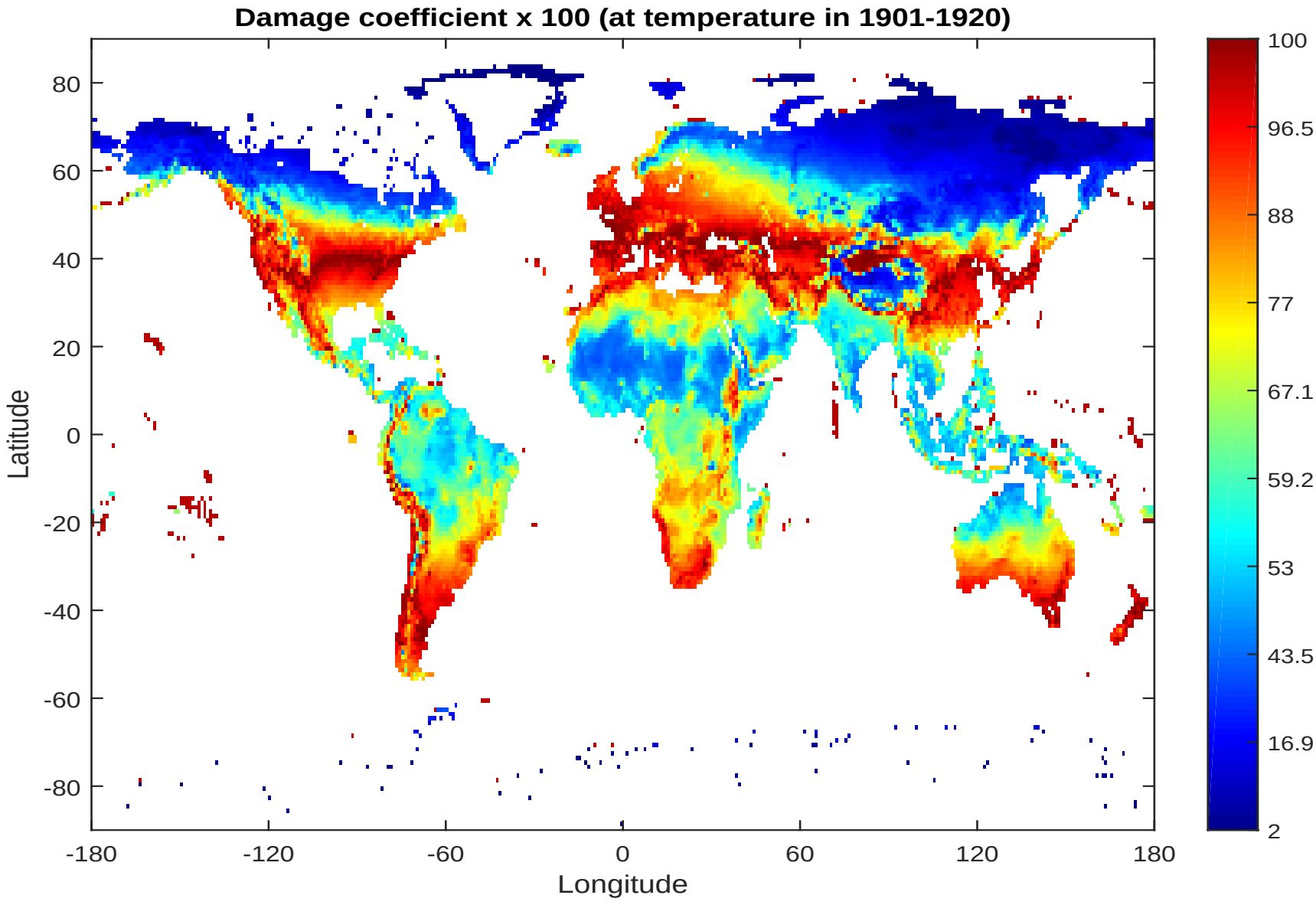
gdp distribution across 1 minus damages


Share of world GDP vs. productivity (as a fraction of optimum)
21.5733
.009839
Share of GDP
.25
.5
.75
.9
.995
Productivity

population distribution across 1 minus damages


Share of world population vs. productivity (as a fraction of optimum)
10.4166
.007063
Share of population
.25
.5
.75
.9
.995
Productivity

global map with 1 minus damage coefficients


Damage coefficient x 100 (at temperature in 1901-1920)
Latitude
80
60
40
20
0
-20
-40
-60
-80
Longitude
-180
-120
-60
0
60
120
180
100
96.5
88
77
67.1
59.2
53
43.5
16.9
2

The economic model

- Forward-looking consumers and firms in each region determine their consumption, saving, and energy use.
- No migration.
- Neoclassical production technologies, different TFPs both exogenously and due to climate.
- Energy as an input: coal, produced locally, at constant marginal cost (no profits).
- Coal slowly, exogenously replaced by (same-cost) green tech.
- Market structure: two cases.
  - Autarky (regions only linked via emission externality).
  - Unrestricted borrowing/lending (world interest rate clears market).
- Summary: like Aiyagari (1994) and our previous work, though no shocks in this version.
- Adaptation: consumption smoothing and, in case with international markets, capital mobility.

Regional problem

In a recursive equilibrium, region ℓ solves

- $v_t(\omega, A, \bar{k}, S; \ell) =$
  $\max_{k',b'} [U(c) + \beta\, v_{t+1}(\omega', A', \bar{k}', S'; \ell)]$, s.t.

$$
\begin{aligned}
c &= \omega - k' - q_t(\bar{k}, S) b' \\
\omega' &= \max_{e'} [F(k', (1 - D(T_\ell(S')))A', e') - pe')] + \\
&\quad (1-\delta)k' + b' \\
A' &= (1+g)A \\
\bar{k}' &= H_t(\bar{k}, S) \\
S' &= \Phi_t(\bar{k}, S)\,.
\end{aligned}
$$

- Can be interpreted as decentralized equilibrium.
- Set up to deal with shocks, aggregate and/or local.

Calibration

Economic parameters:

- Annual time step, log utility, $\delta = 10\%$, $g = 1\%$, $\beta = 0.985$.
- Production function F is CES in $k^{\alpha}((1-D)AL)^{1-\alpha}$ and Be, with elasticity 0.1 (we do robustness).
- Initial distribution of region-specific capital and level of productivity chosen to: (1) match regional GDP per capita in 1990 and; (2) equalize MPK across regions.
- Price of coal and B chosen to match: (1) total carbon emissions in 1990; and (2) energy share of 5% along a balanced growth path.
- Green energy replaces coal slowly (logistic).

Computation

- Richard Feynman: Imagine how much harder physics would be if electrons had feelings!
- Transition + heterogeneity = nontrivial fixed-point problem.
- Use mostly well-known methods but heterogeneity vast:
  - exogenous TFP
  - wealth/capital
  - ℓ captures entire path of future regional TFP endogenous to climate (this feature NOT one-dimensional);
    - we don't actually solve 19,235 DP problems
    - but so much heterogeneity that we need to solve 700 DPs
    - and then nonlinearly interpolate decision rules between 700 "types"

Experiments

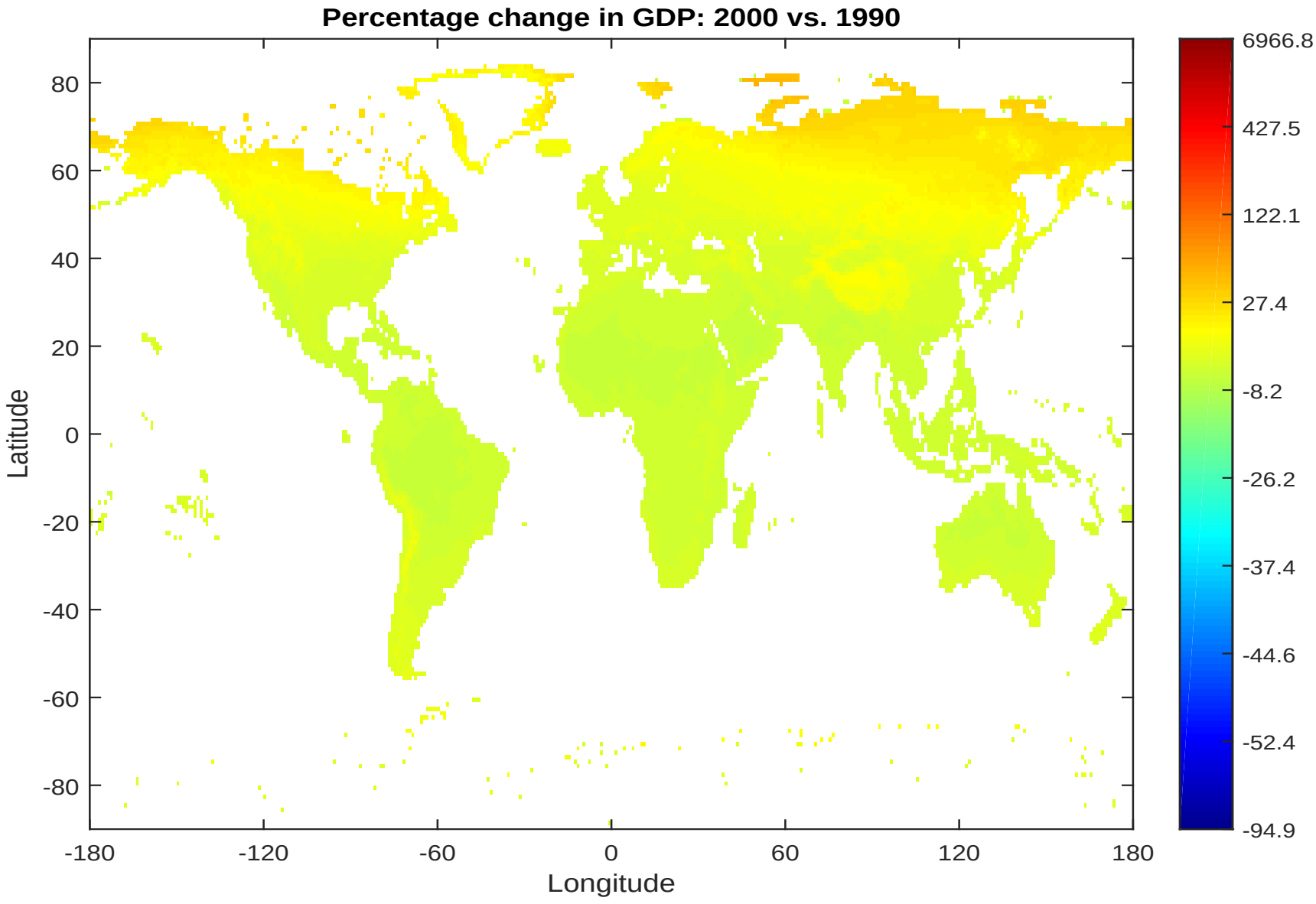
- Laissez-faire.
- Main policy experiment: all regions impose a modest common carbon tax, financed locally (no transfers implied).

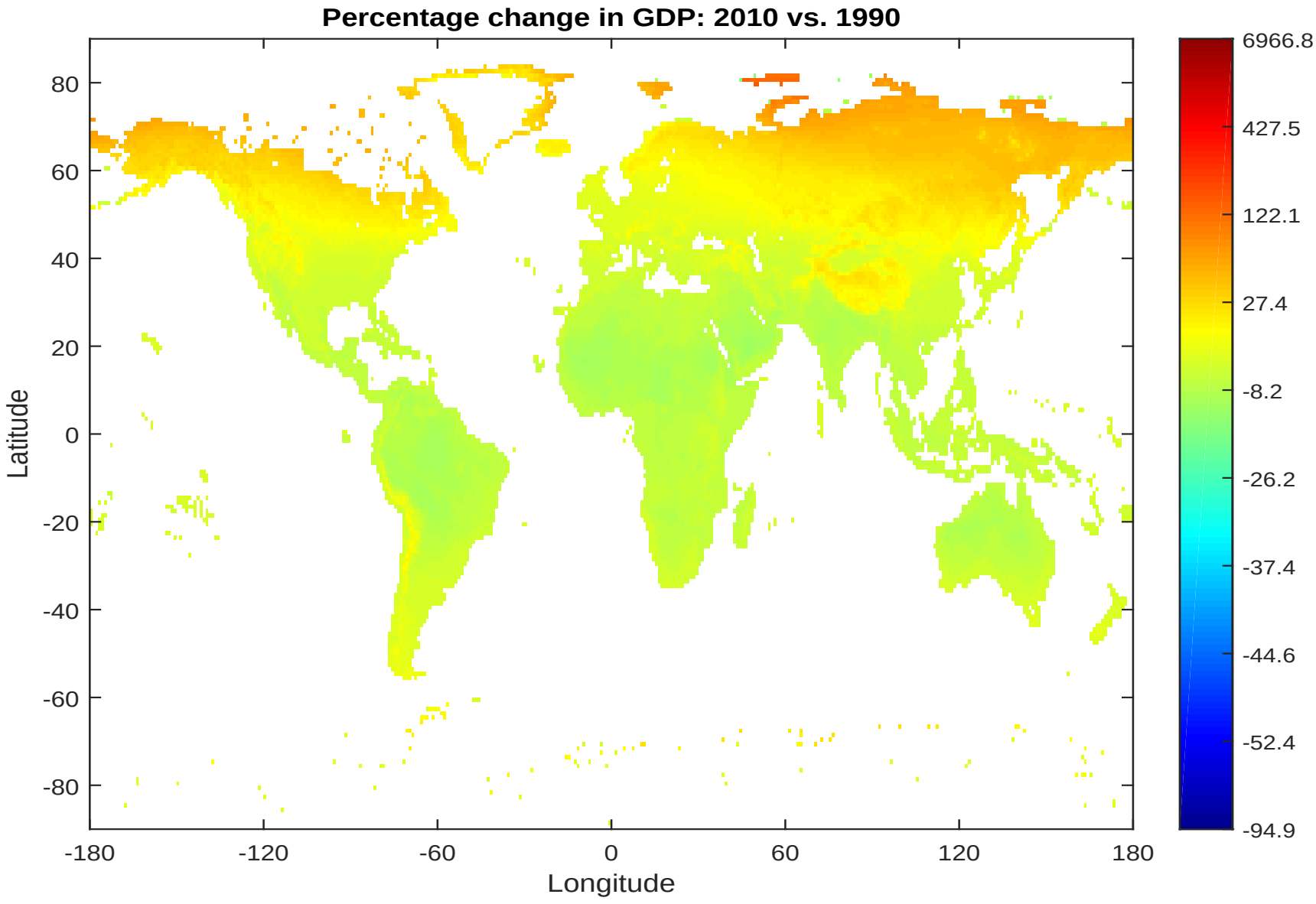
Throughout: focus on relative effects, not aggregates.

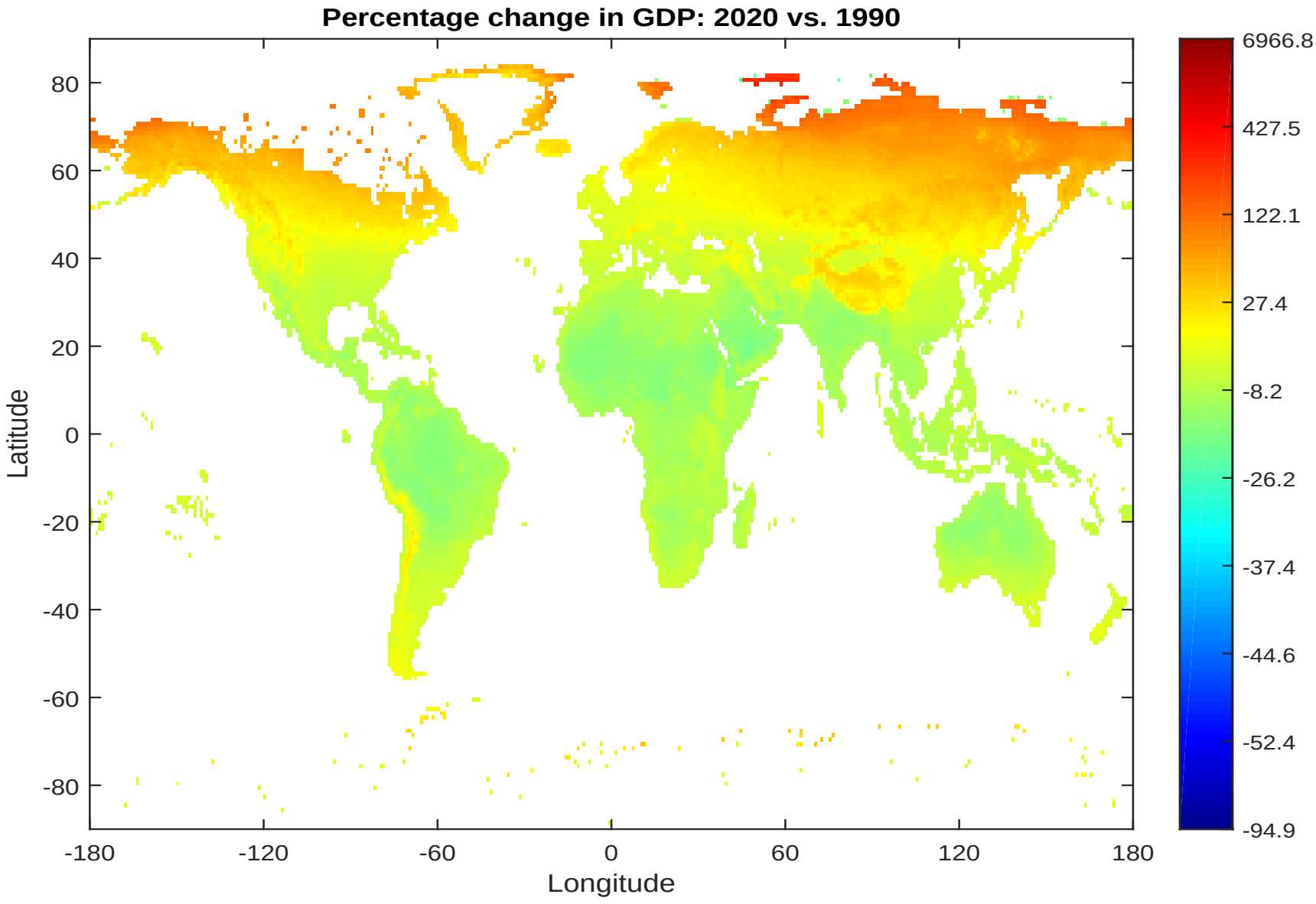
Main findings

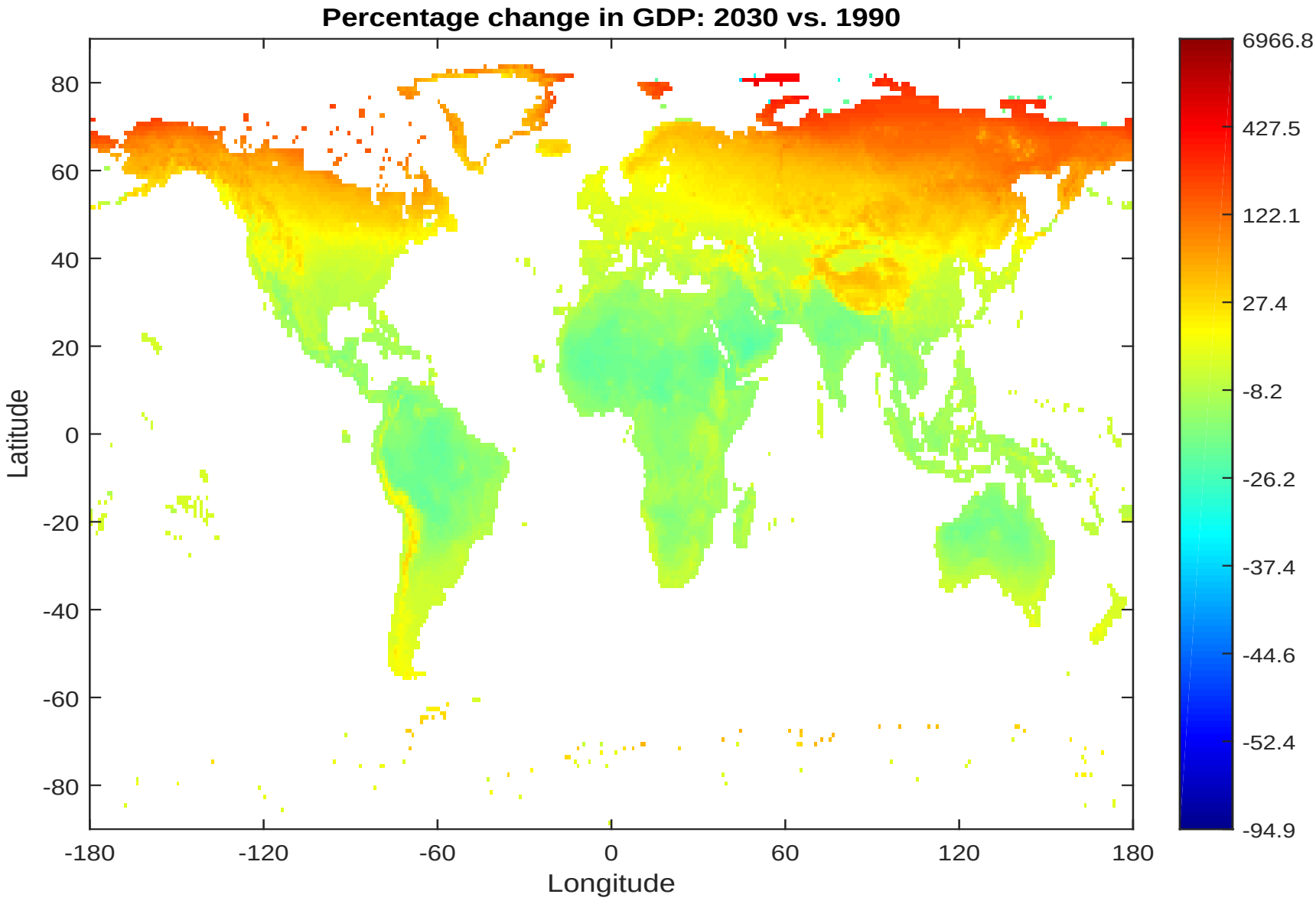
- Climate change affects regions *very* differently. Stakes big at regional level.
- Though a tax on carbon would affect welfare positively in some average sense, huge disparity of views: 55% of regions for tax, 45% against.
- Findings almost identical for two extreme market structures (autarky and international capital markets).

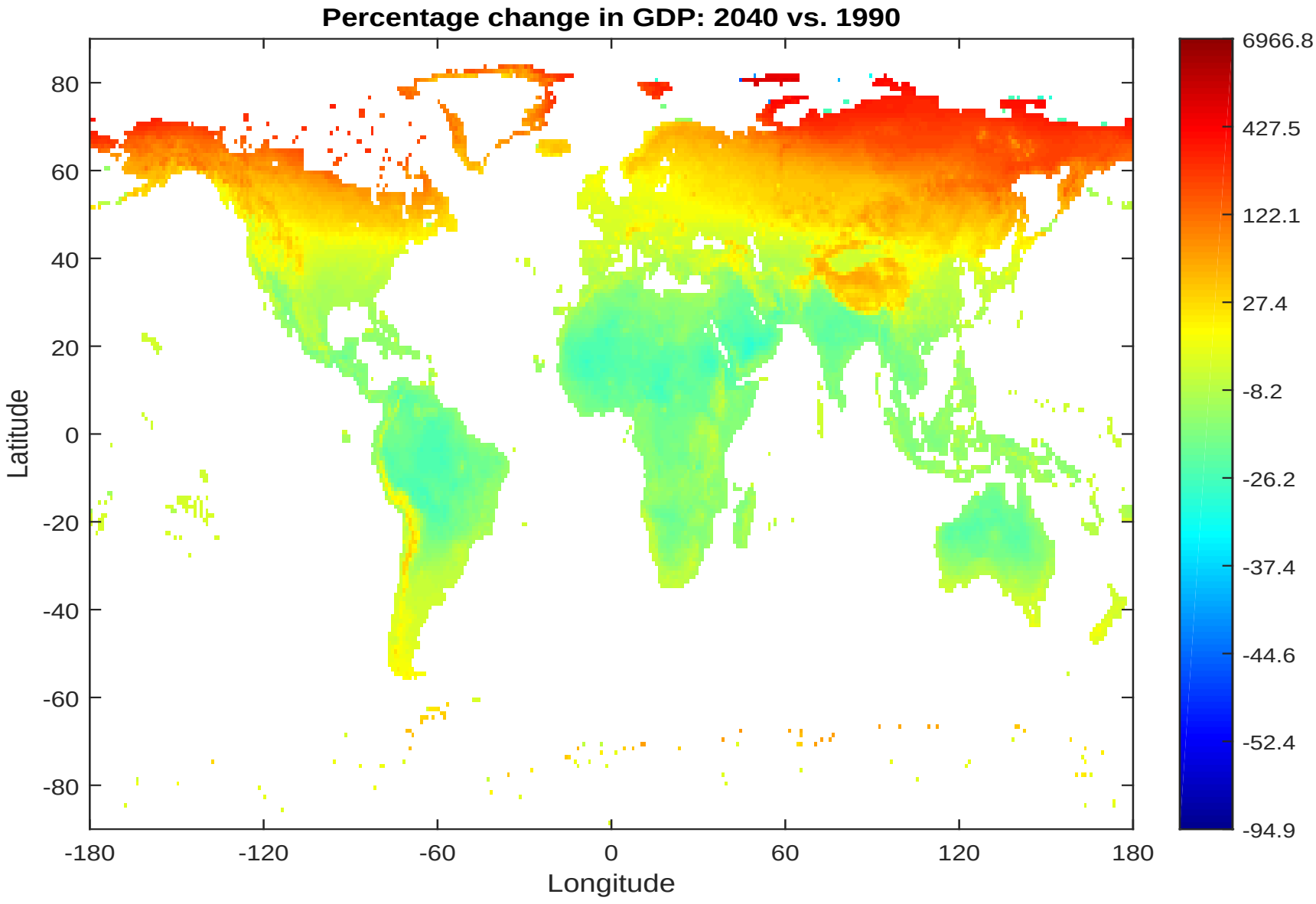
movie: percentage change in gdp, laissez-faire

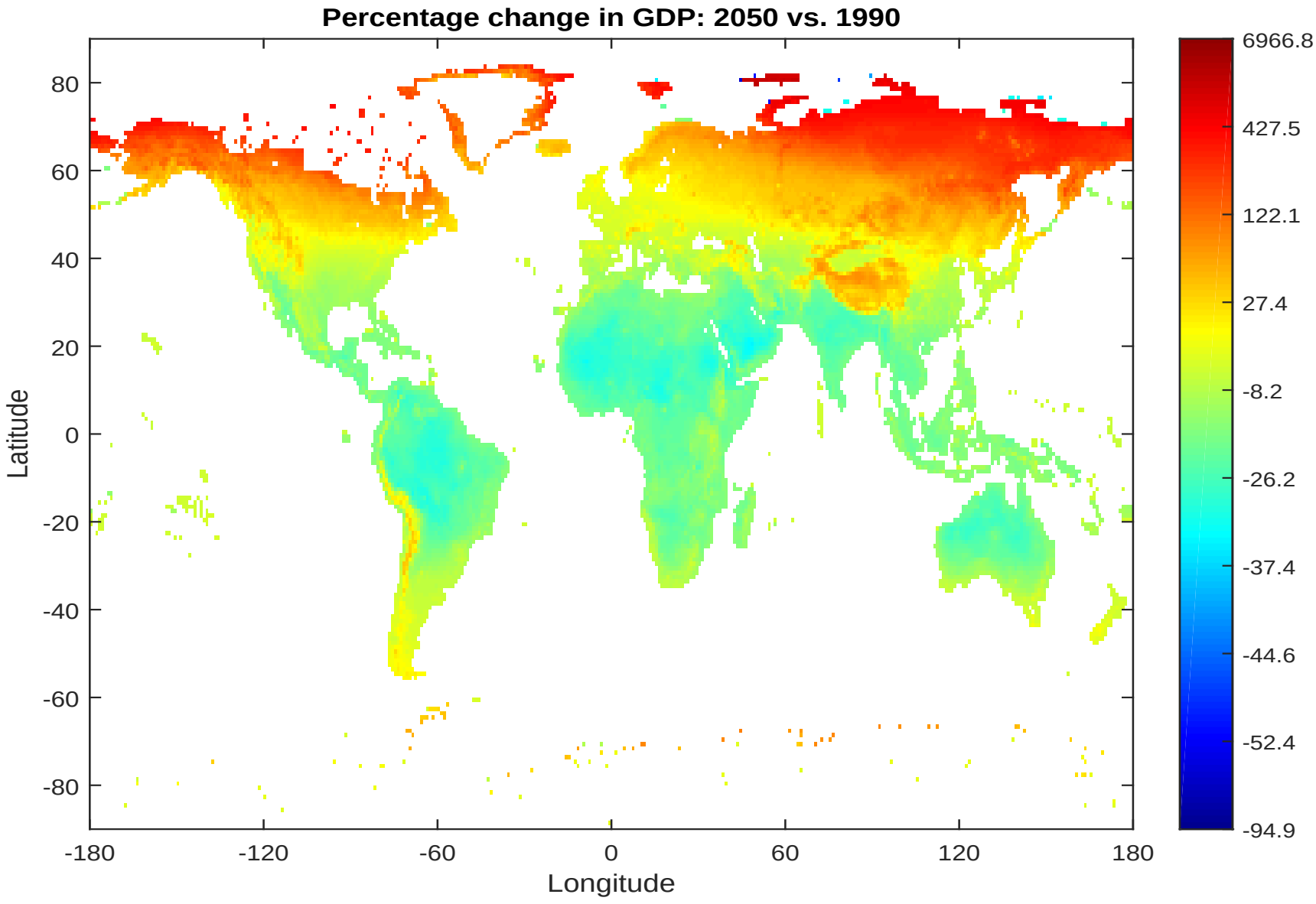

Percentage change in GDP: 2000 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

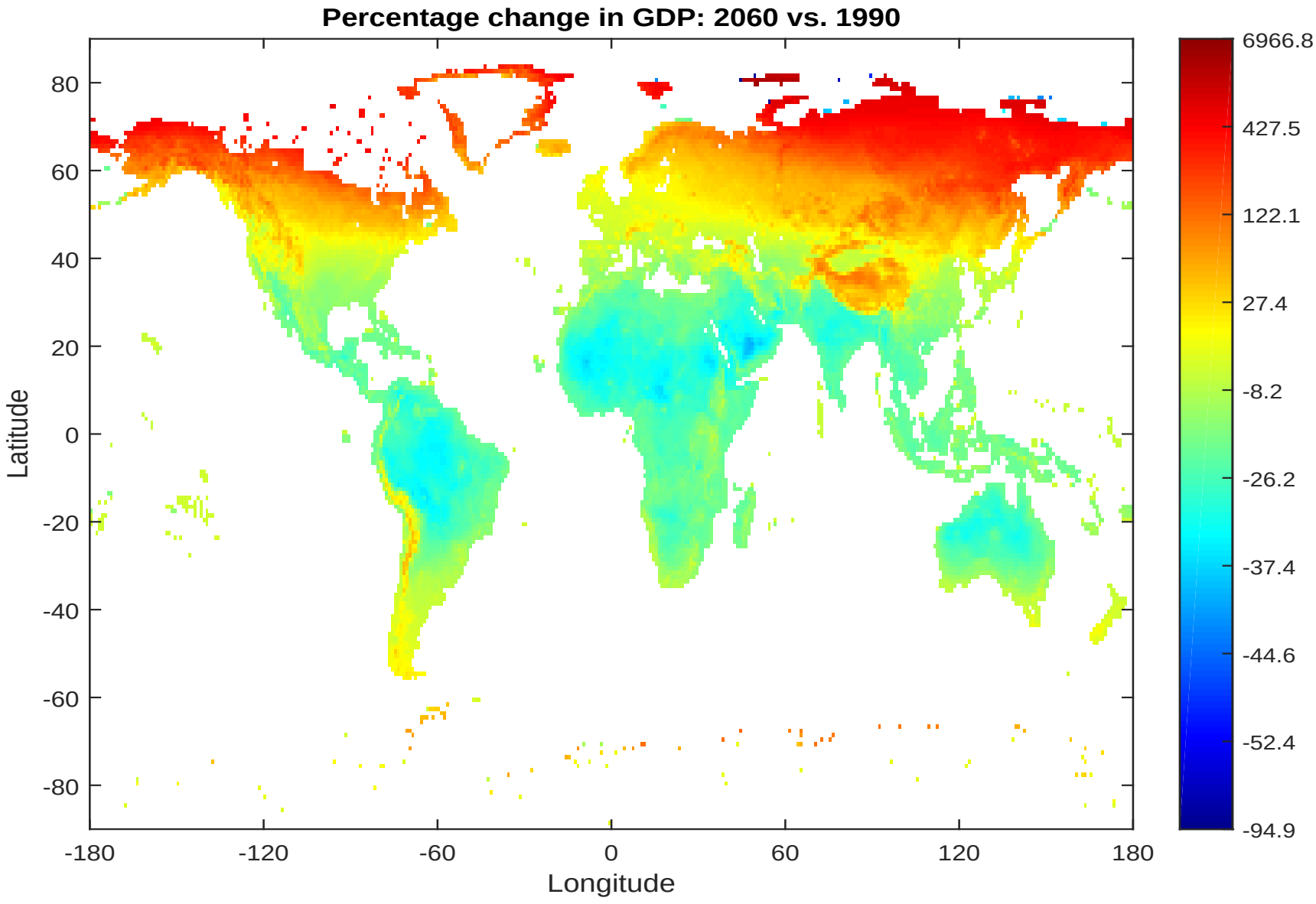

Percentage change in GDP: 2010 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

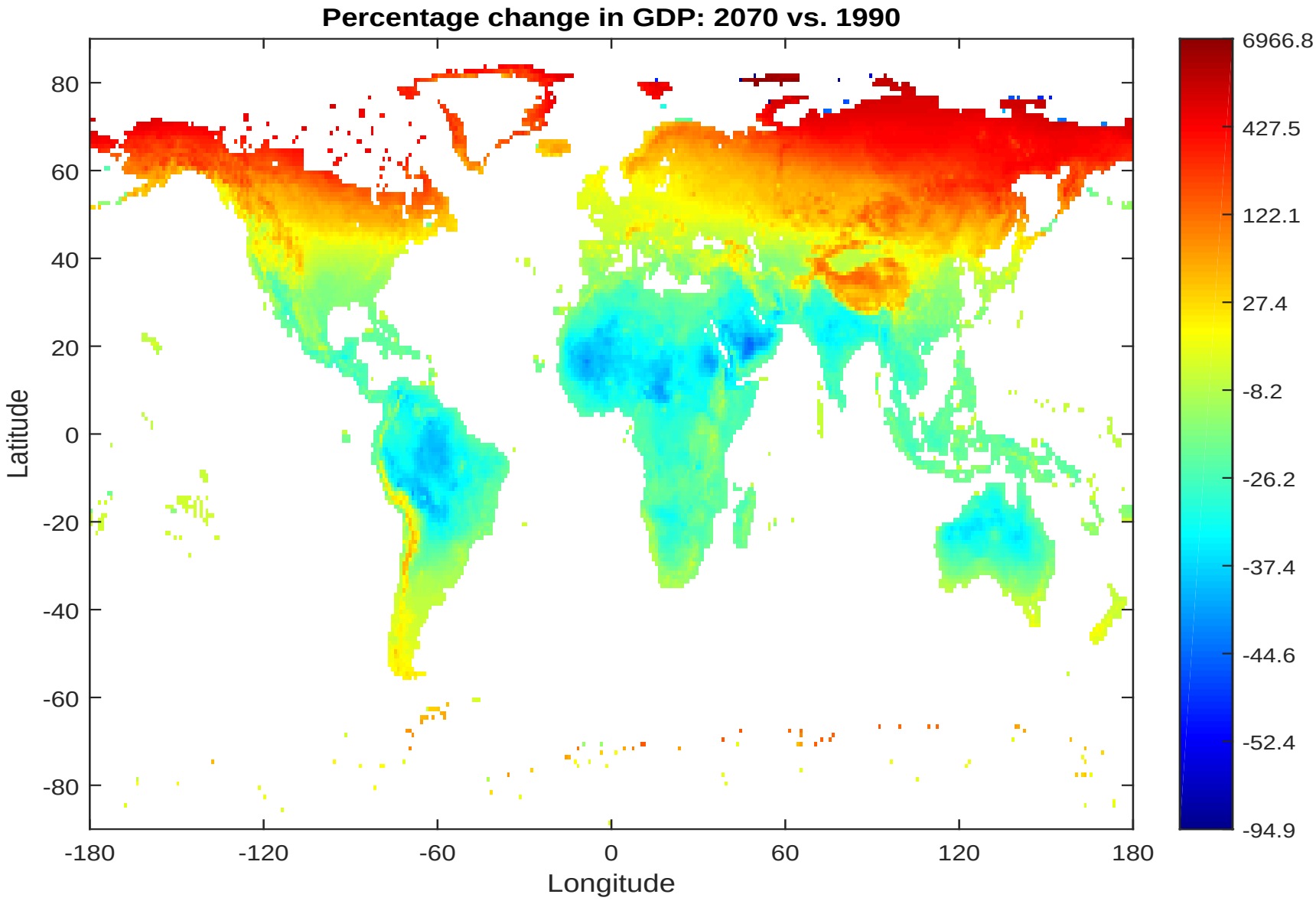

Percentage change in GDP: 2020 vs. 1990
Latitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
Longitude
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

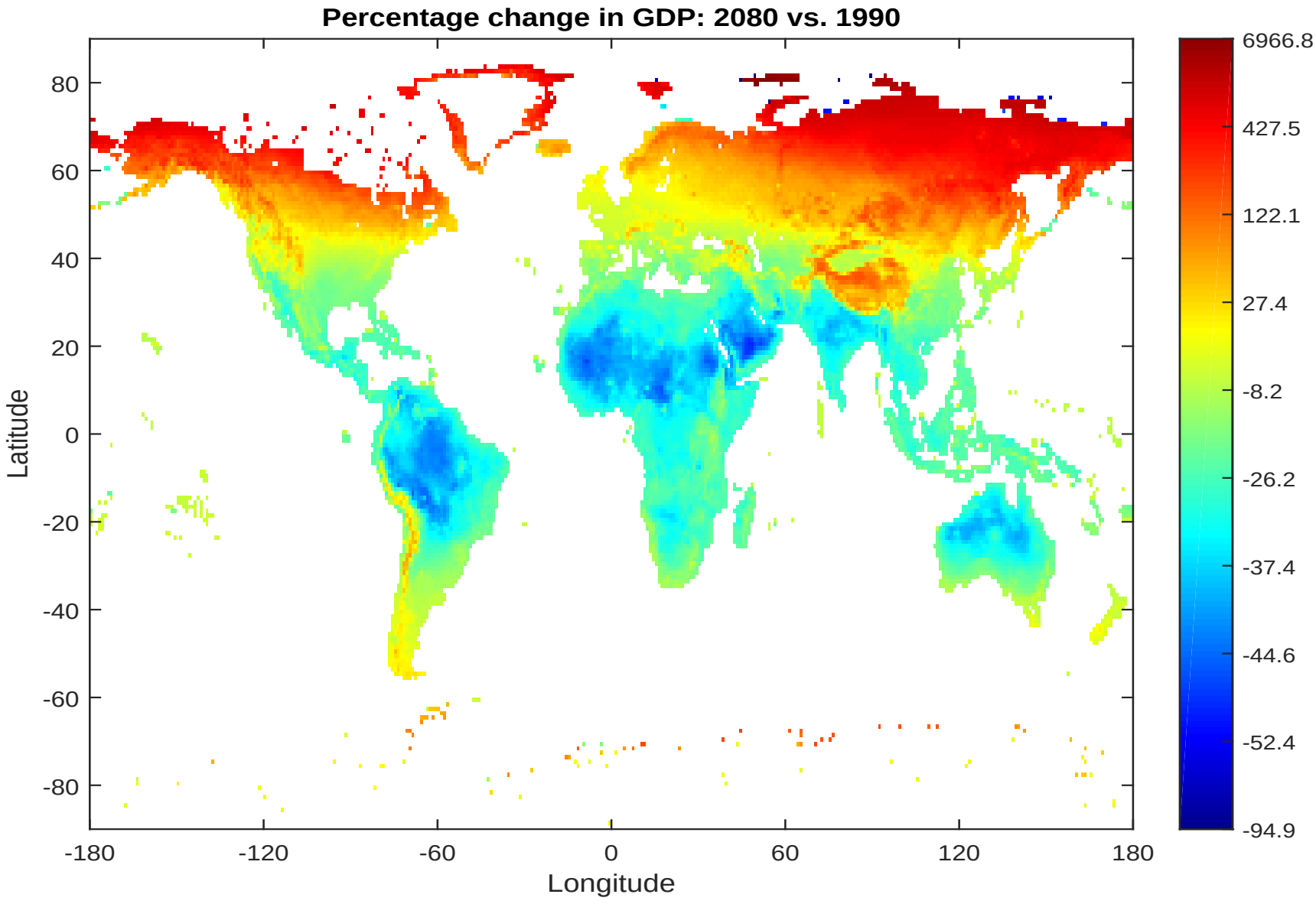

Percentage change in GDP: 2030 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

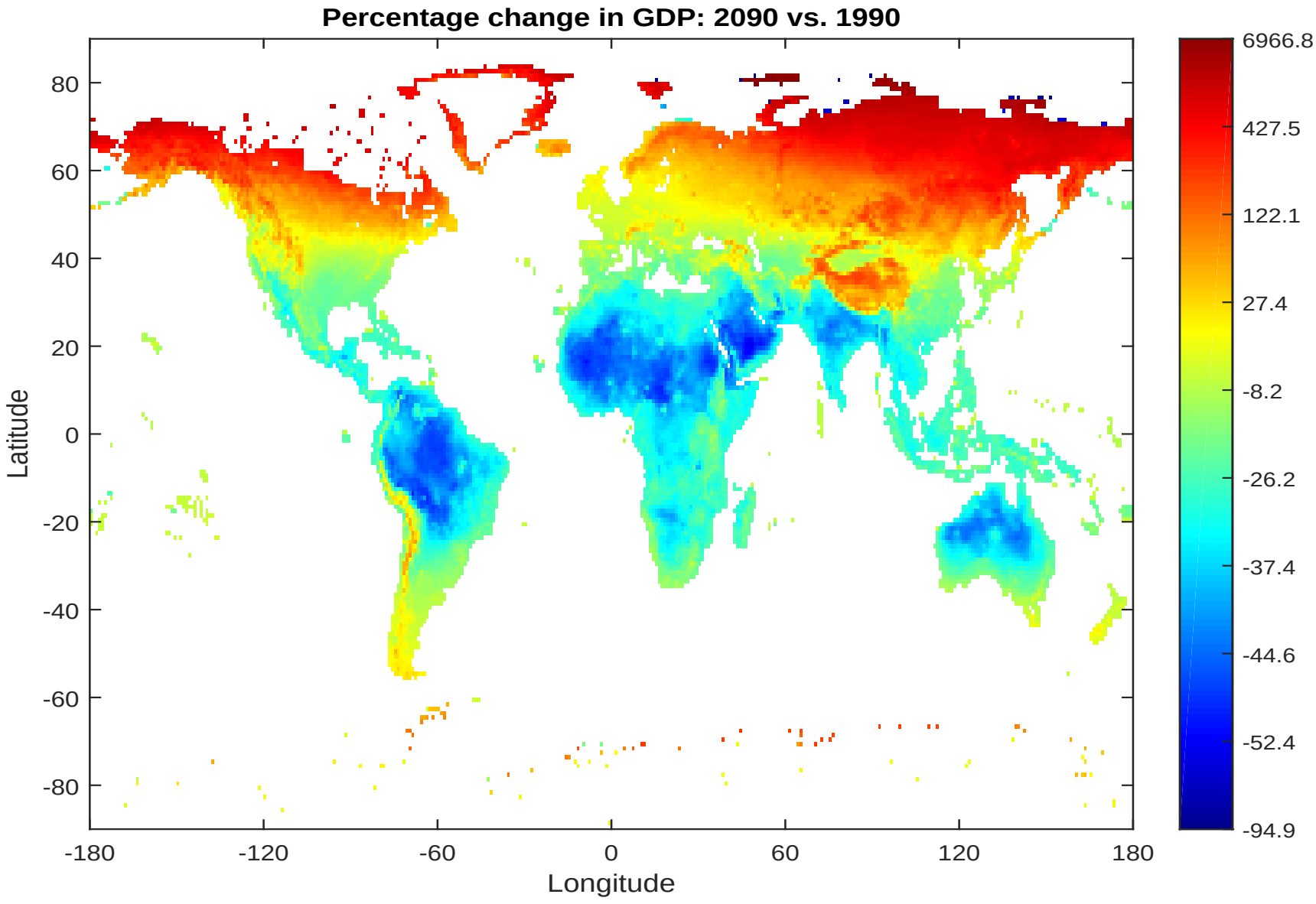

Percentage change in GDP: 2040 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

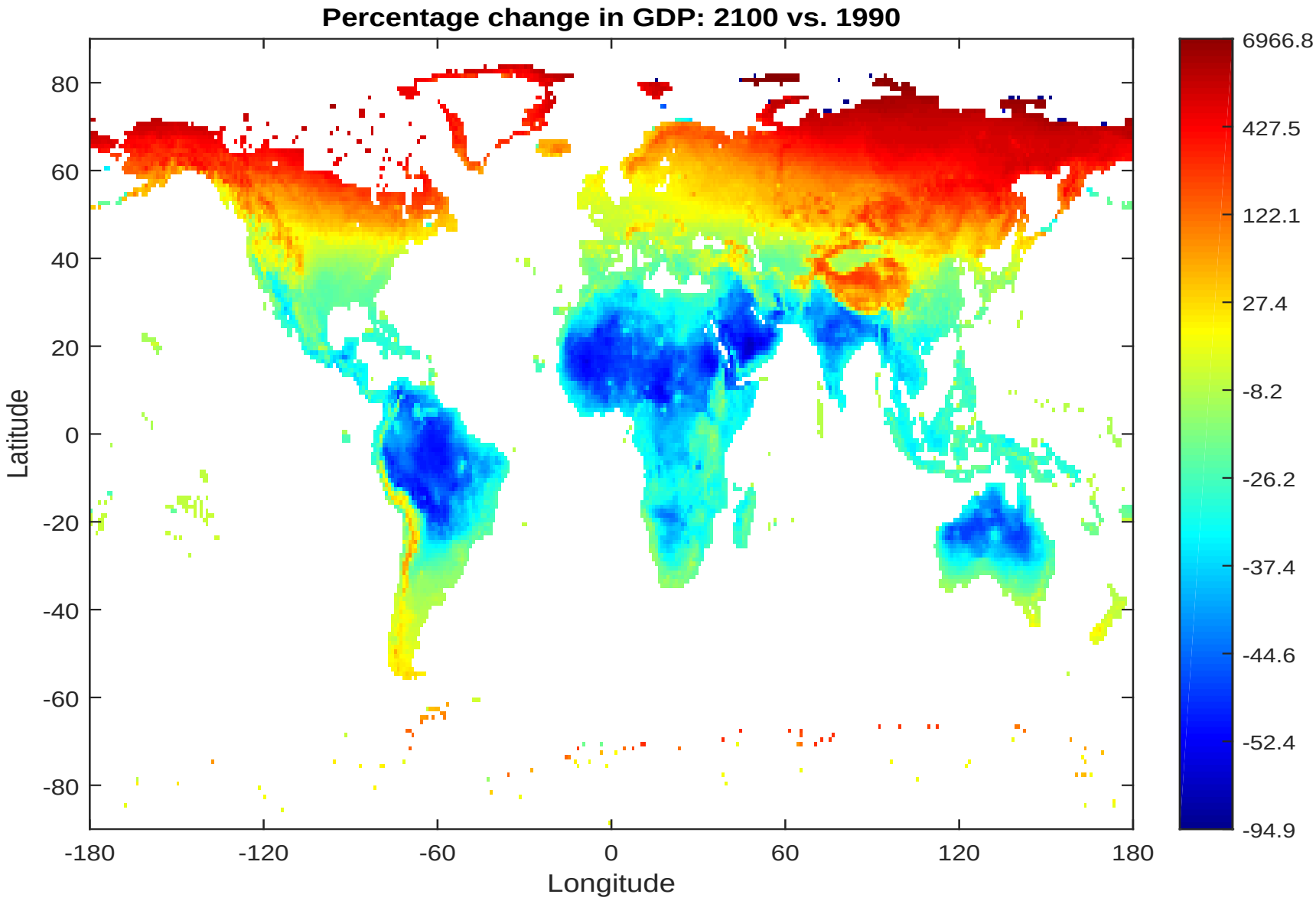

Percentage change in GDP: 2050 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

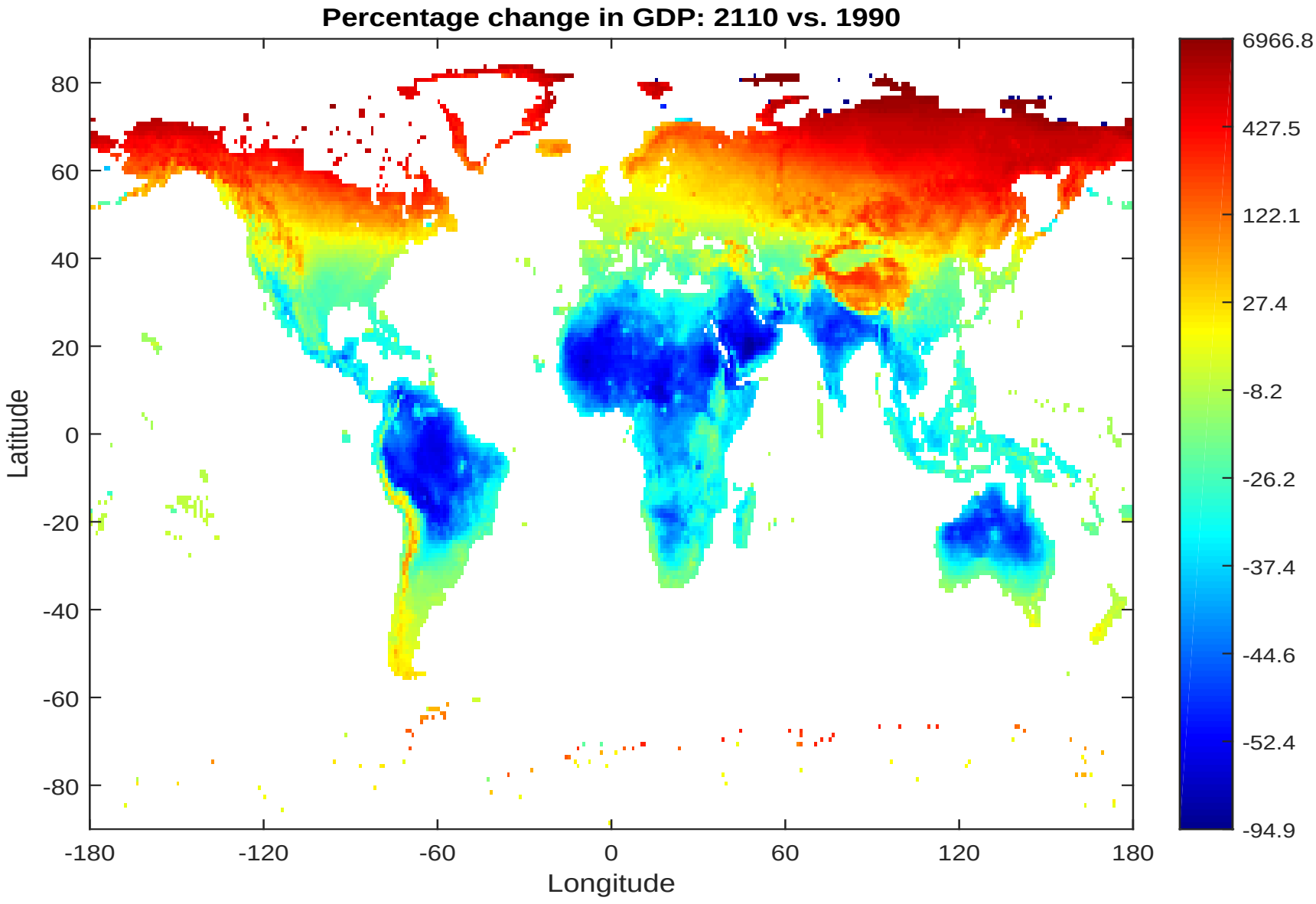

Percentage change in GDP: 2060 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

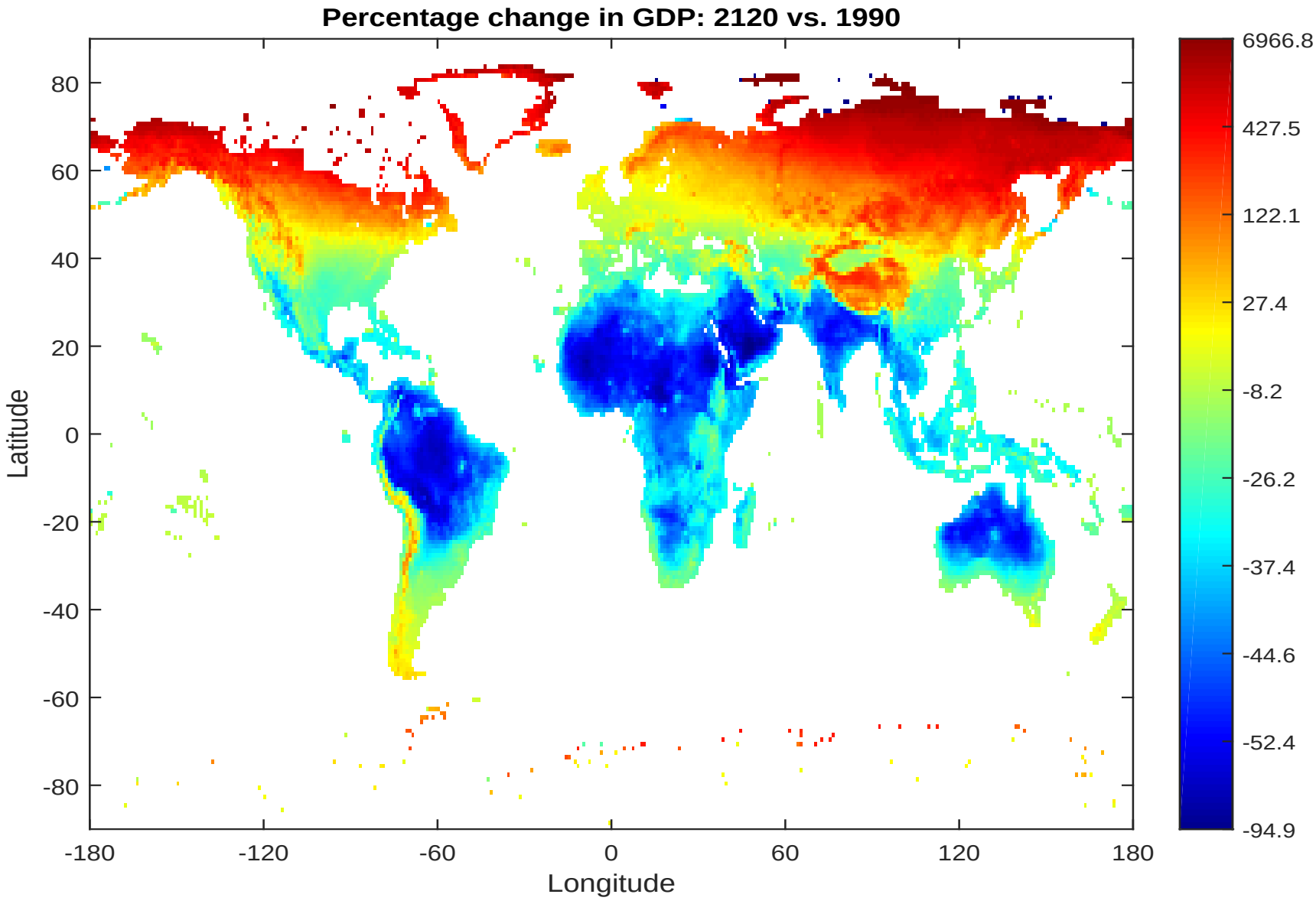

Percentage change in GDP: 2070 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2080 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2090 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2100 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2110 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2120 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
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122.1
27.4
-8.2
-26.2
-37.4
-44.6
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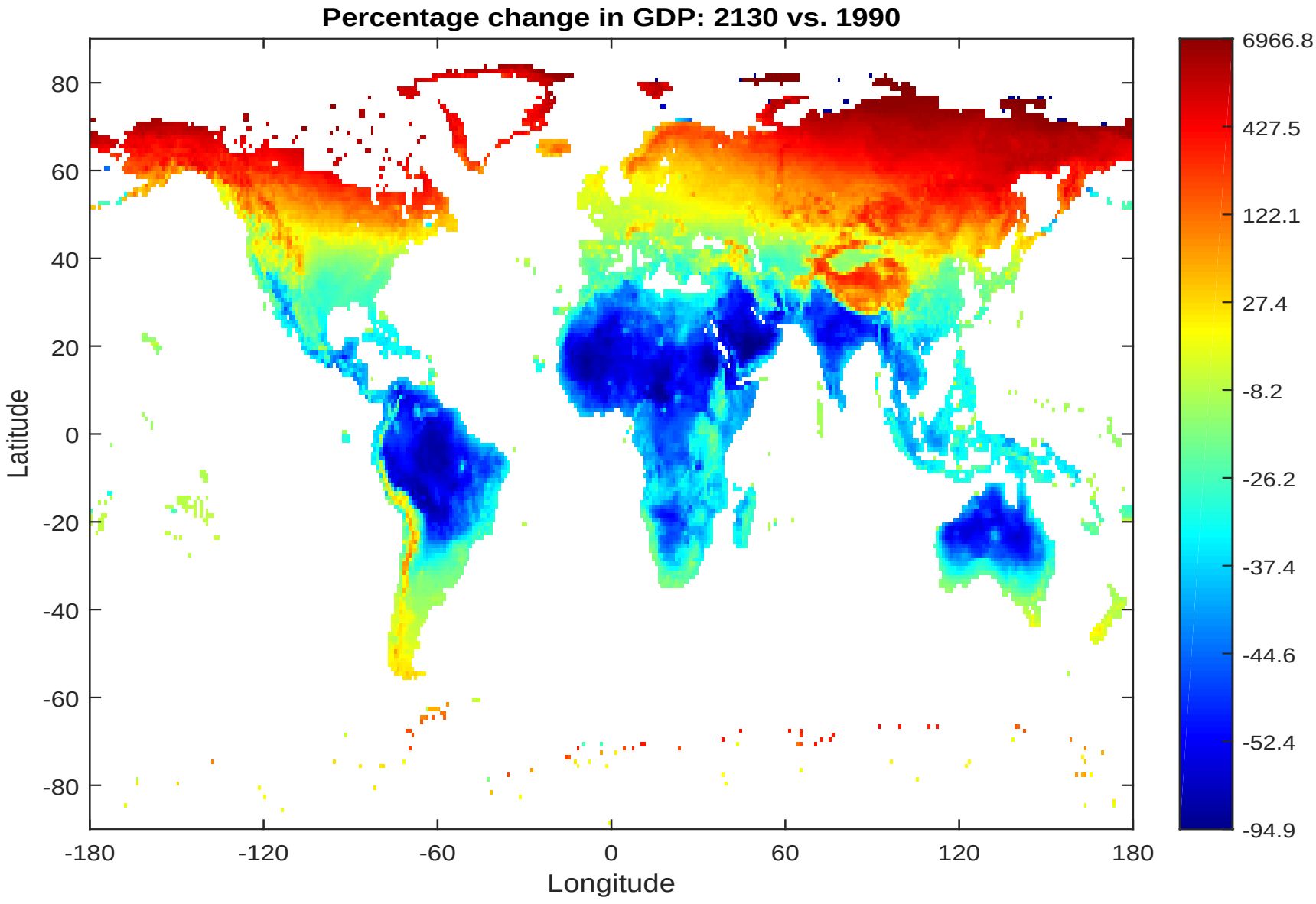
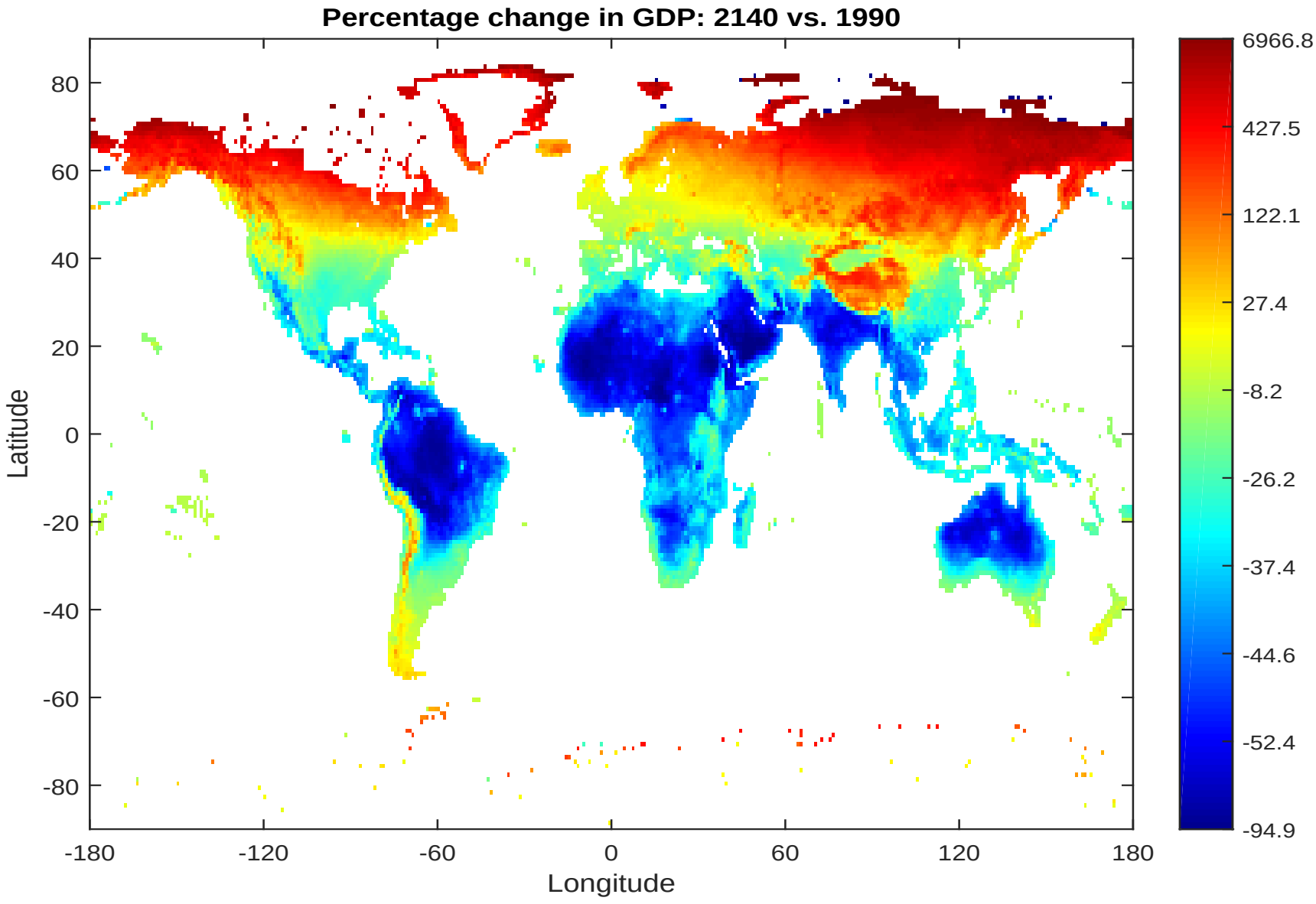
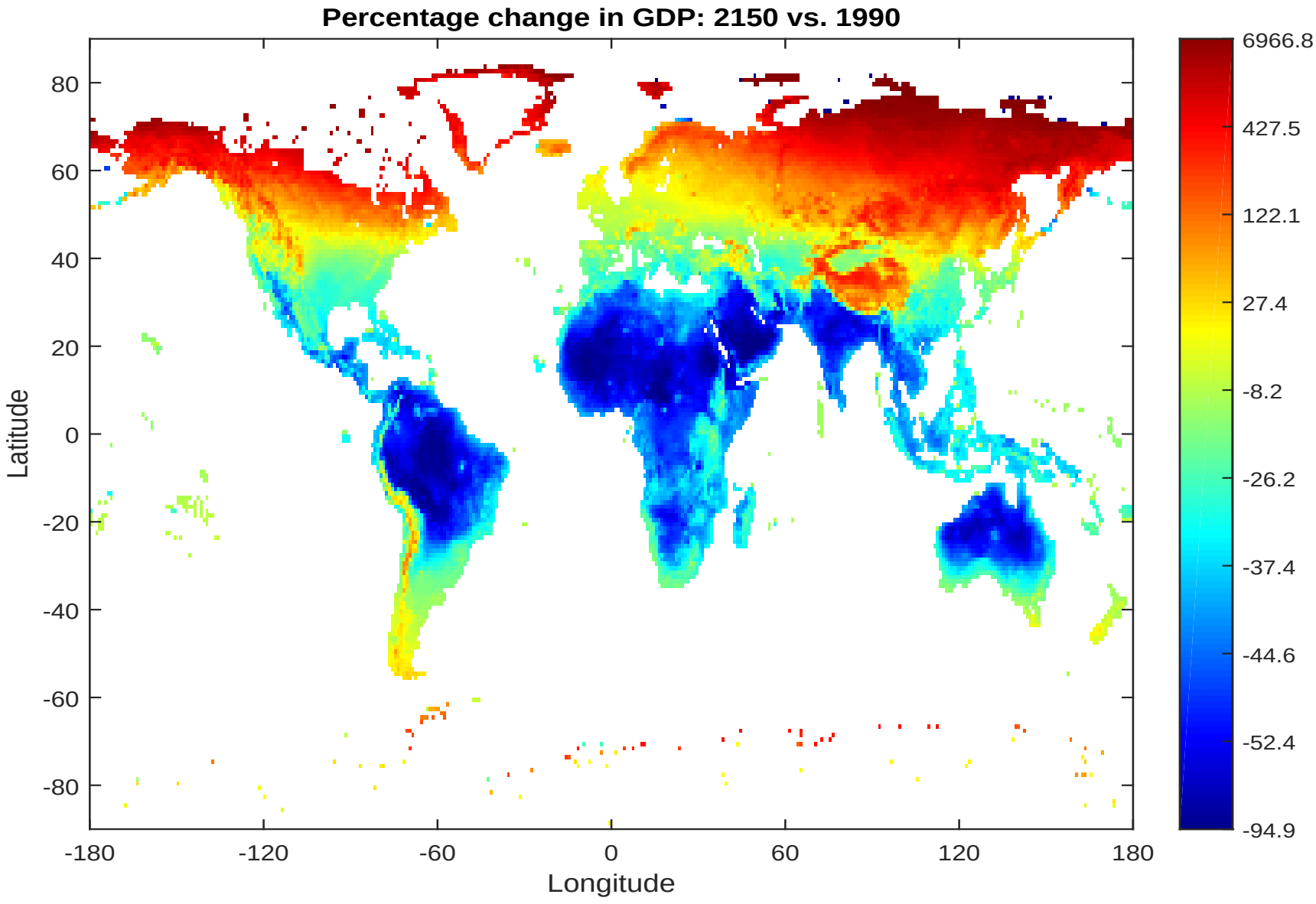
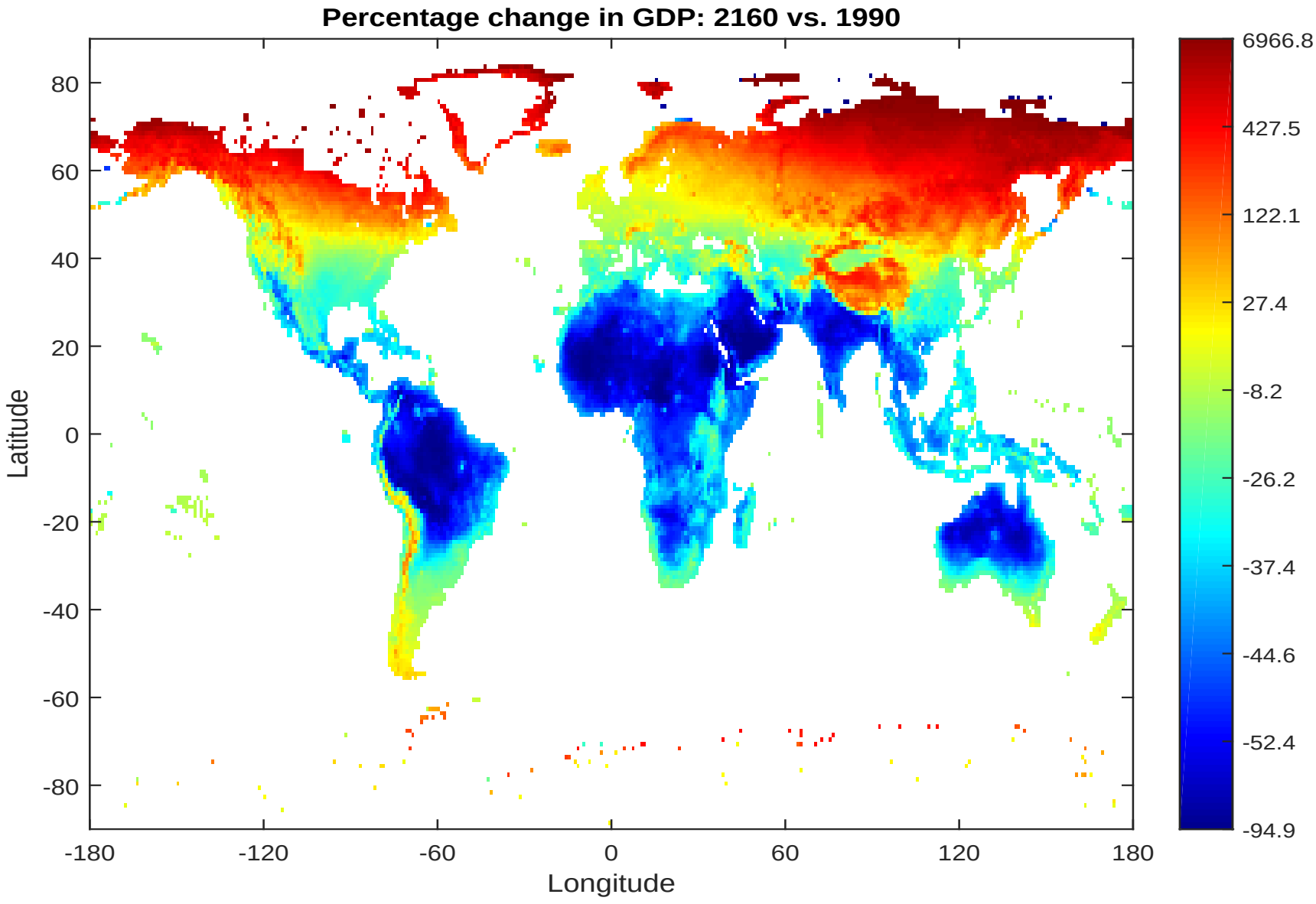
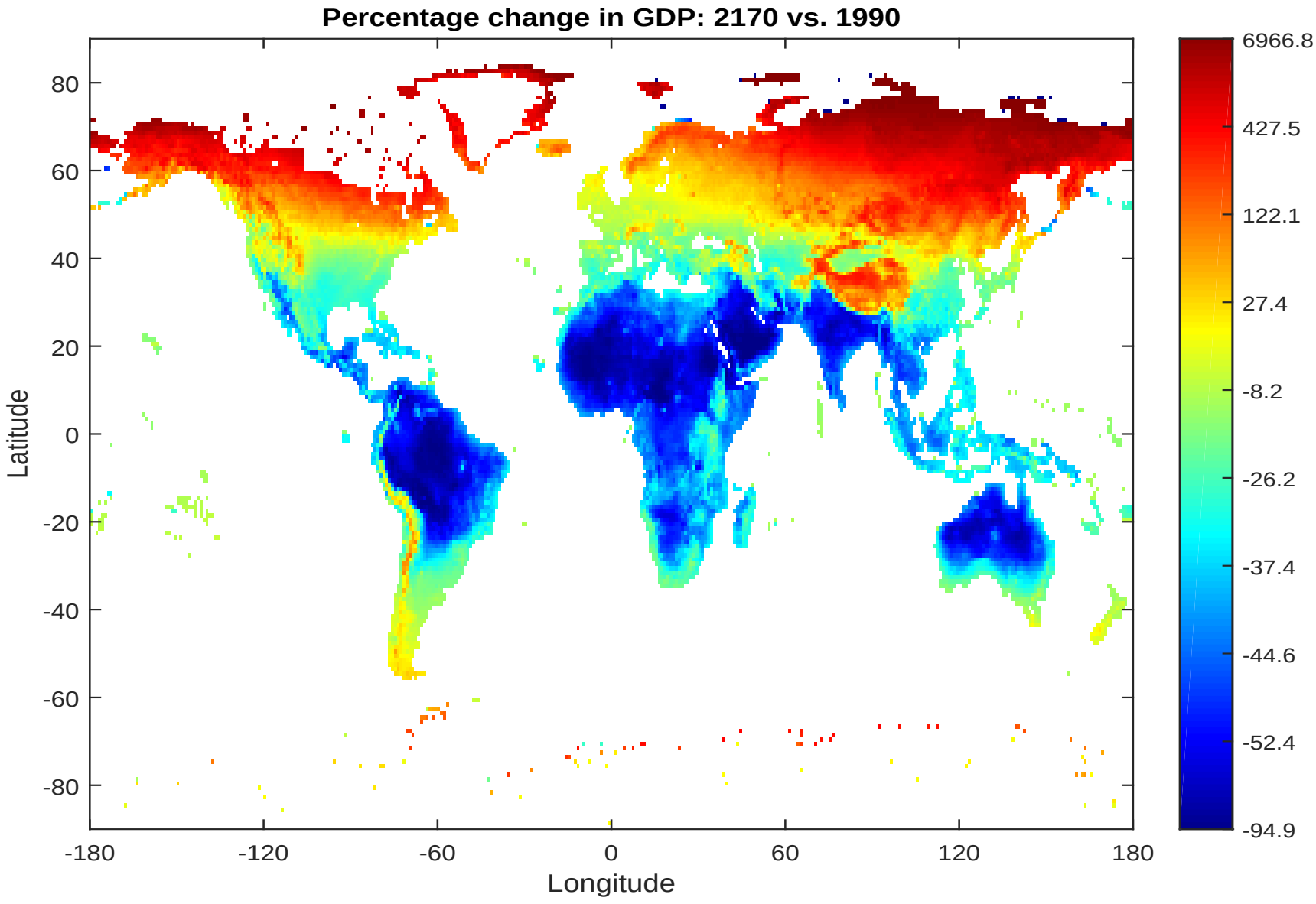
-94.9

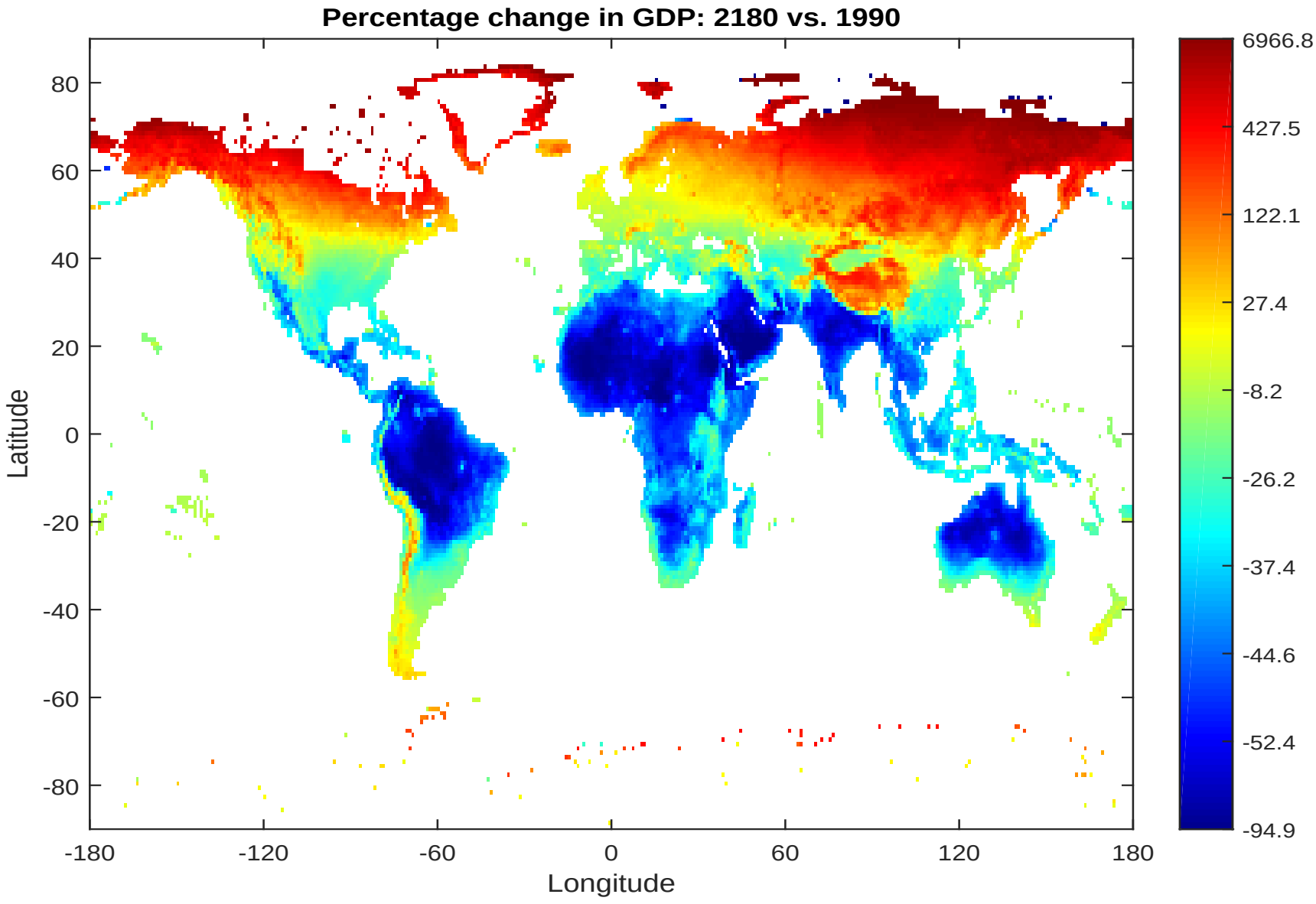

Percentage change in GDP: 2130 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

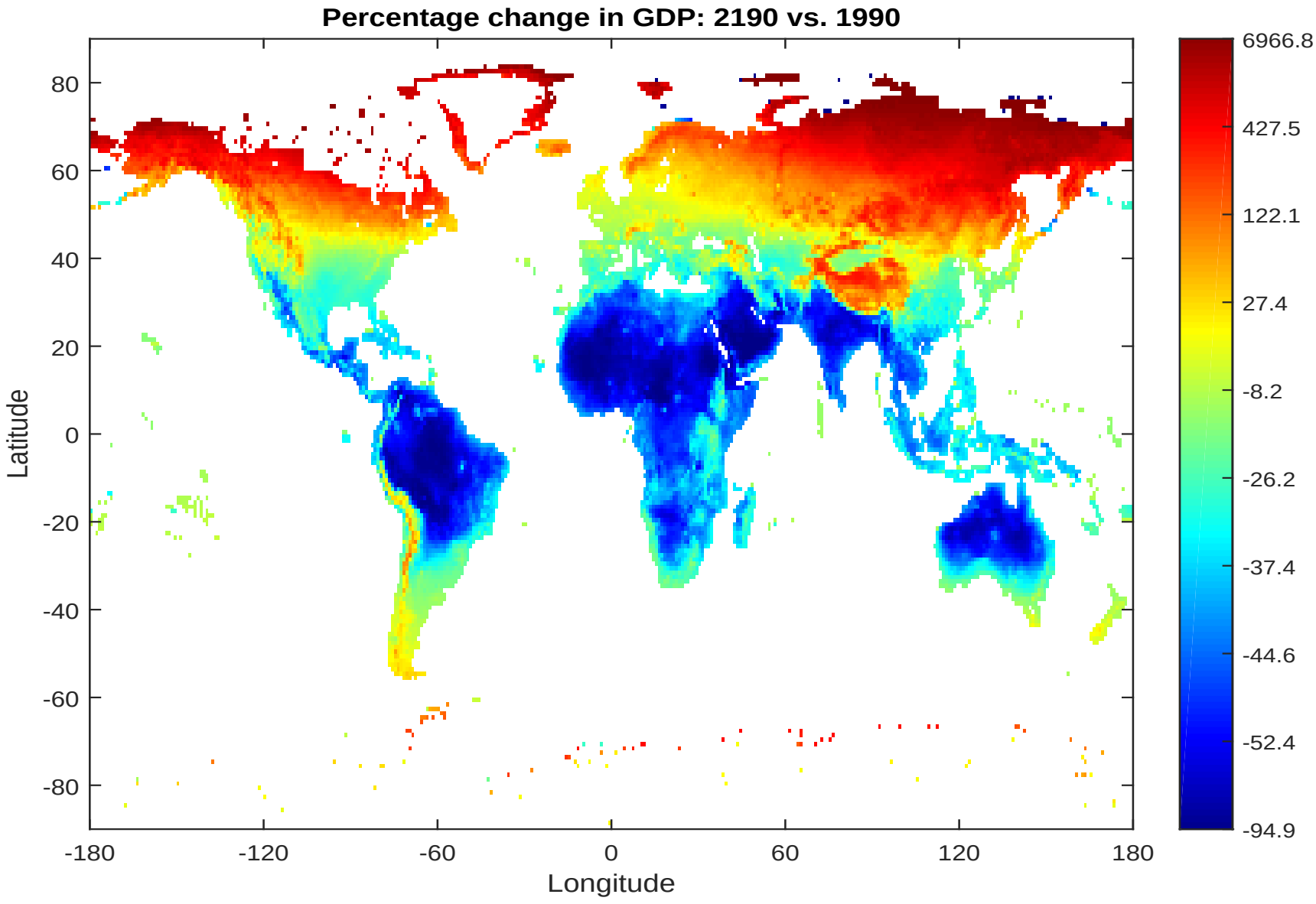

Percentage change in GDP: 2140 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

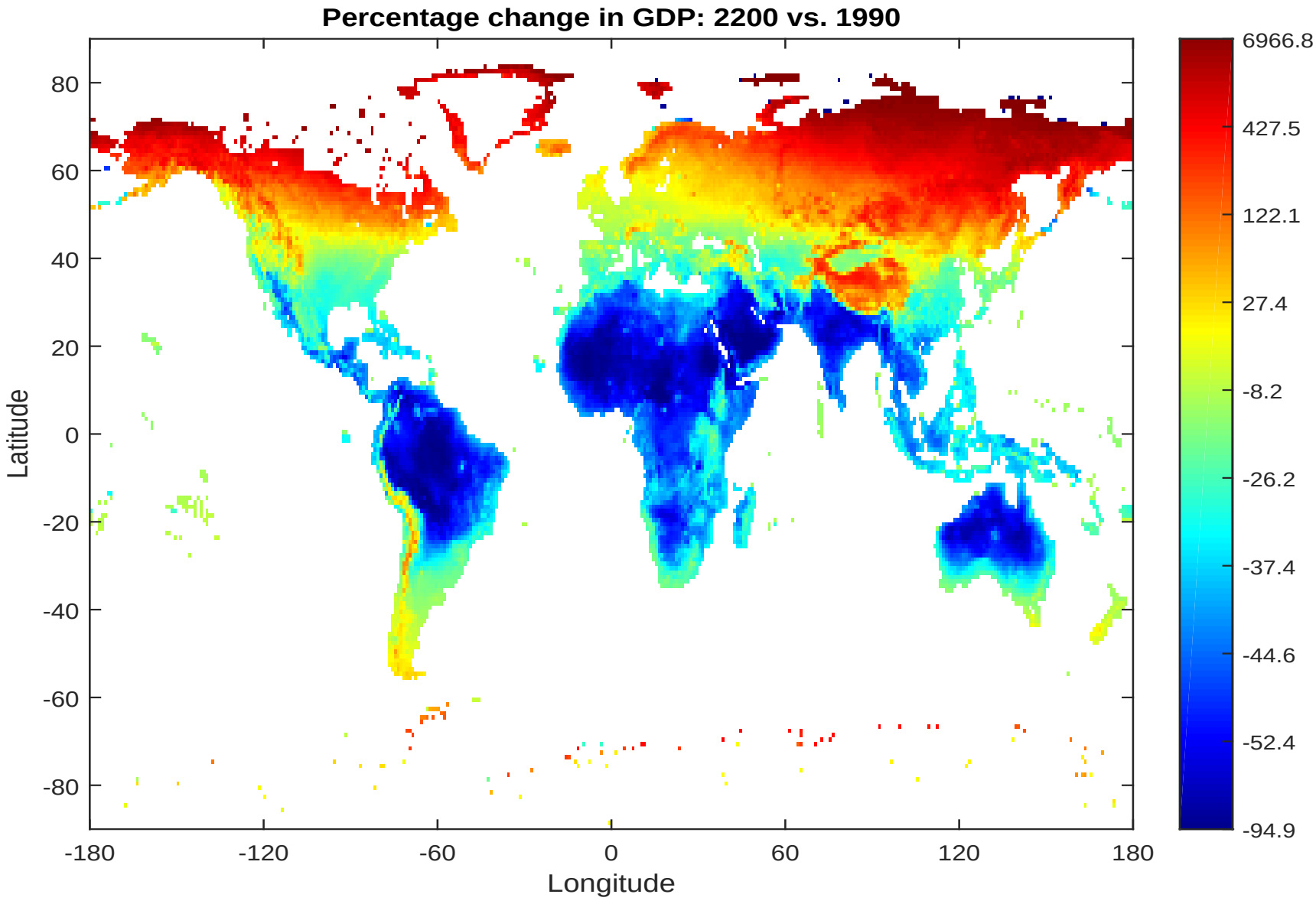

Percentage change in GDP: 2150 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


Percentage change in GDP: 2160 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

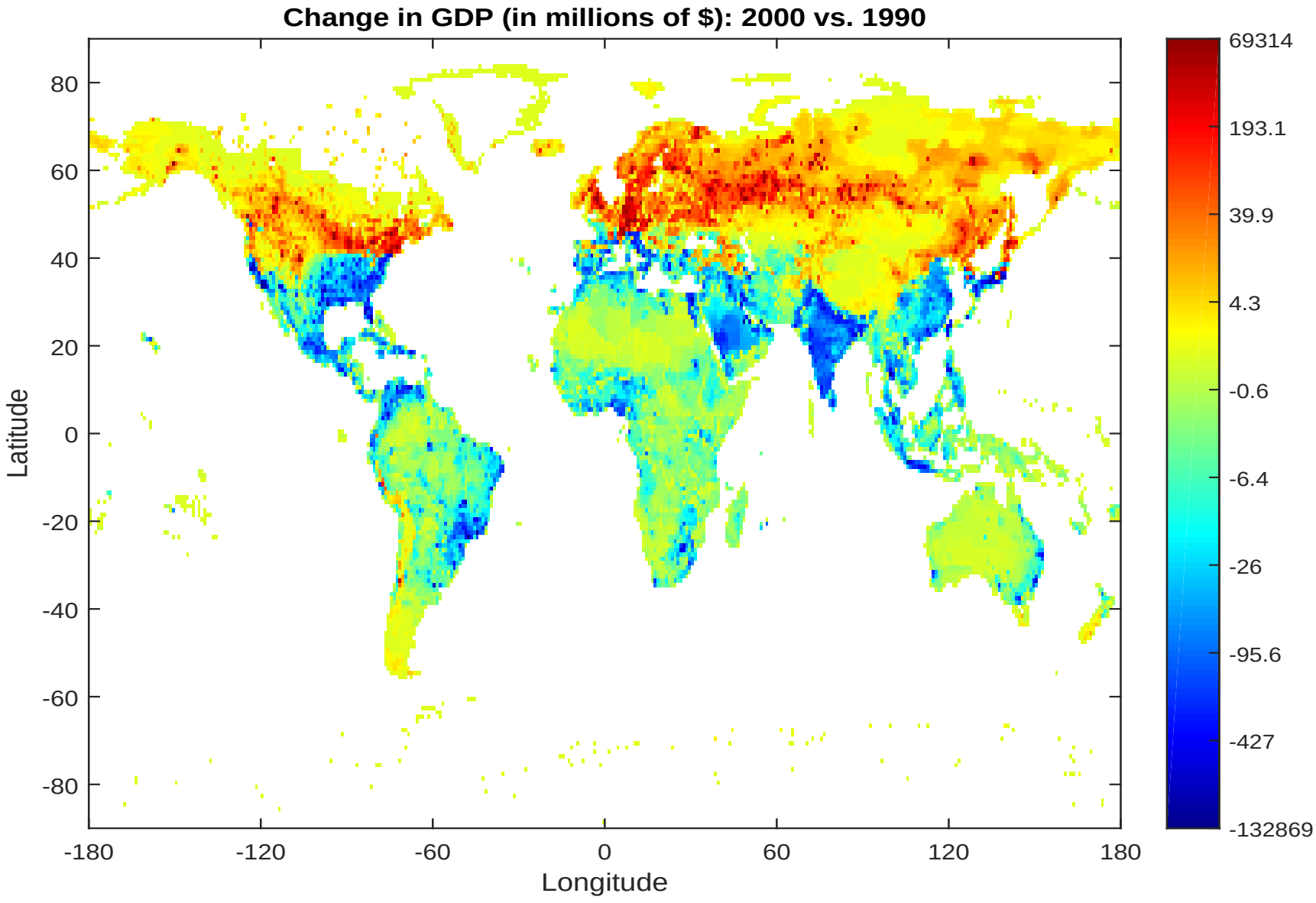

Percentage change in GDP: 2170 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

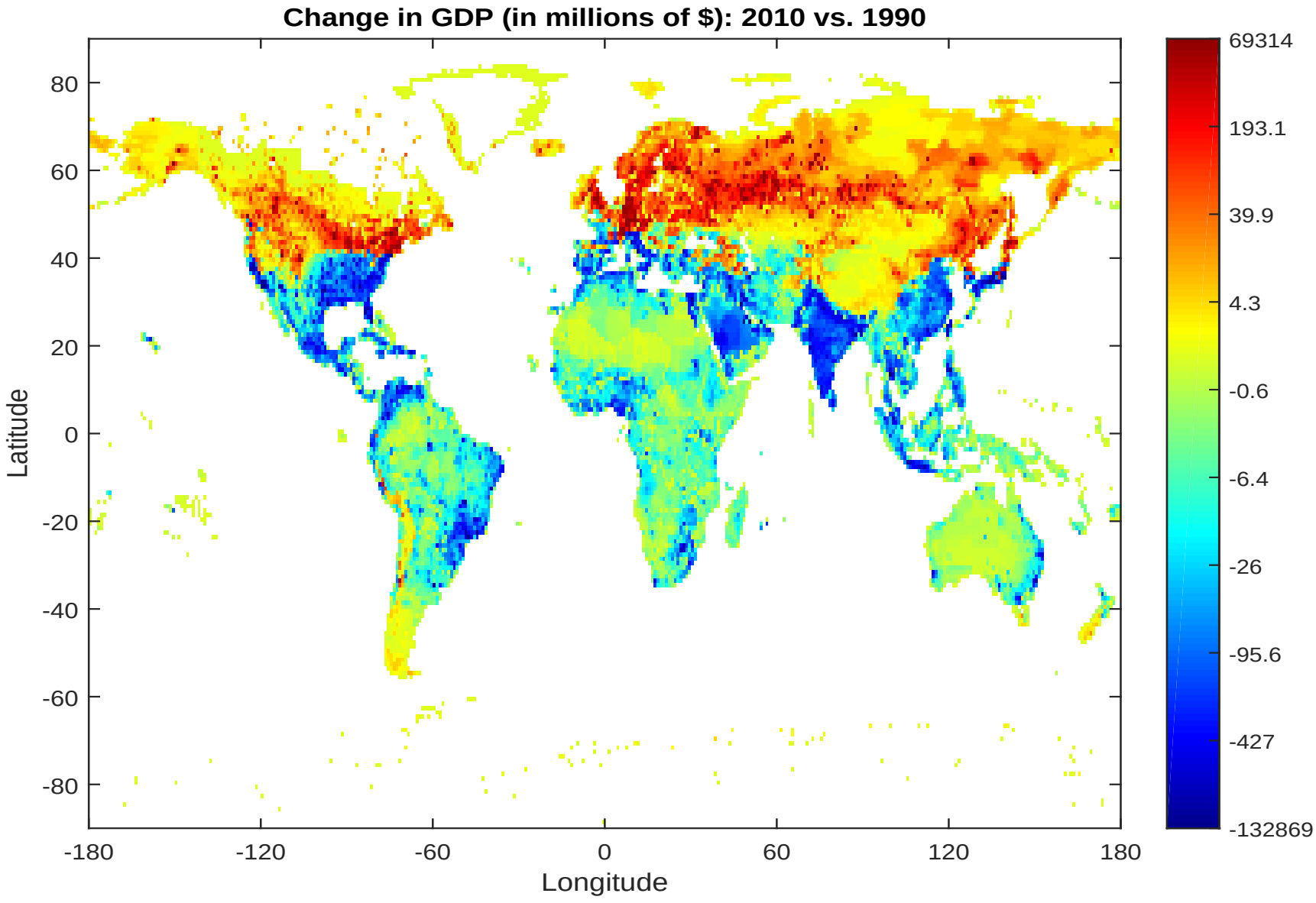

Percentage change in GDP: 2180 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

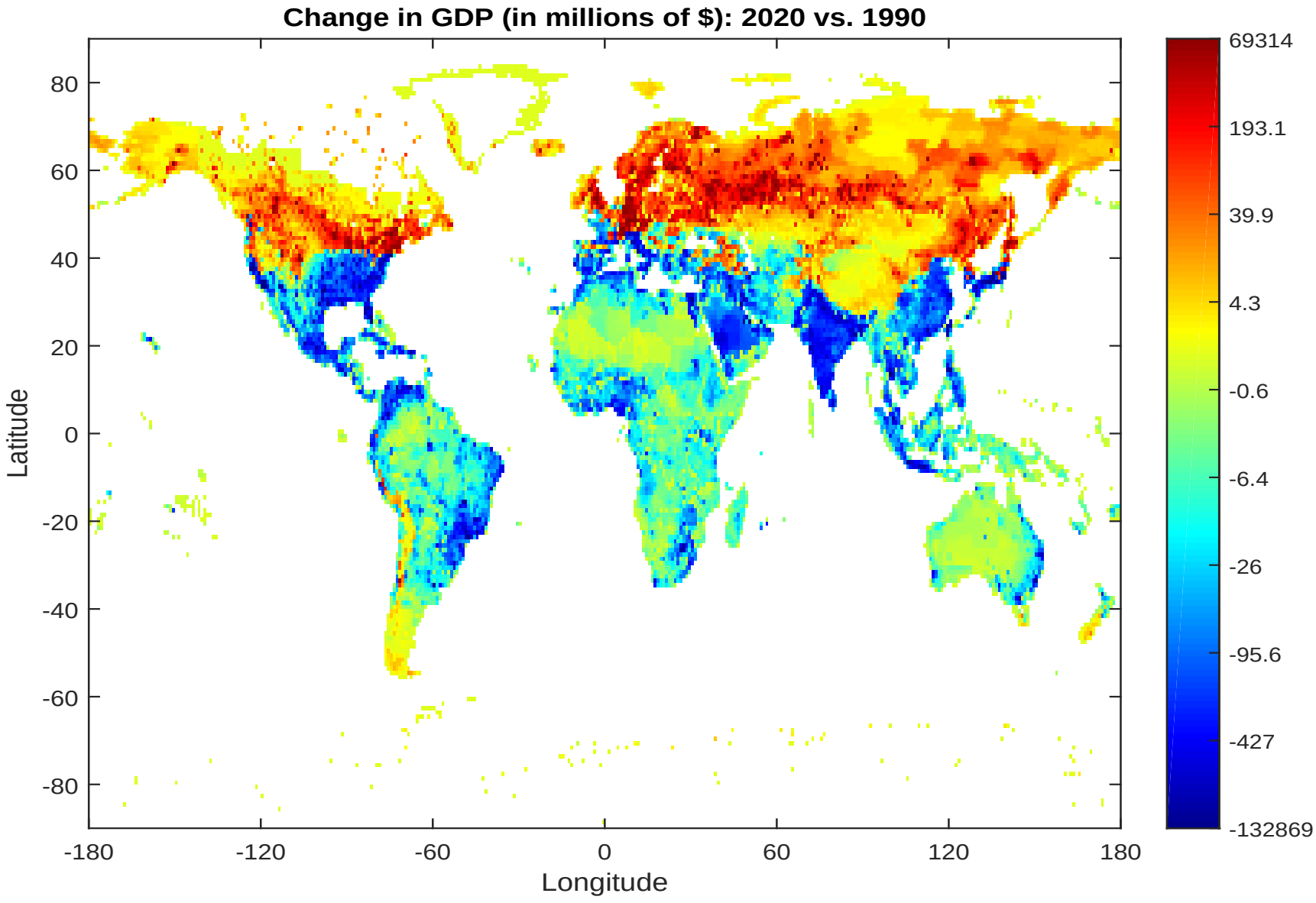

Percentage change in GDP: 2190 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

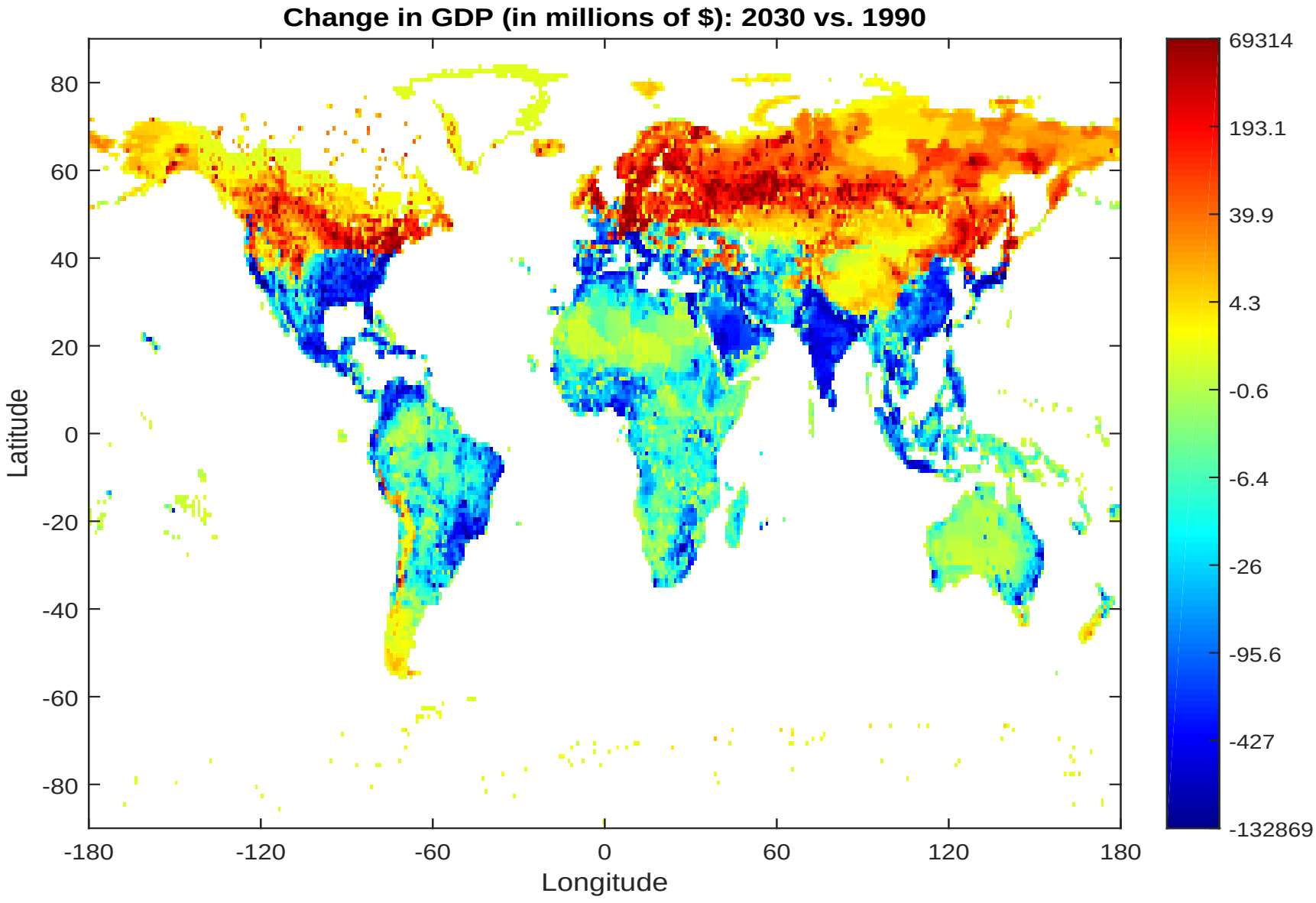

Percentage change in GDP: 2200 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

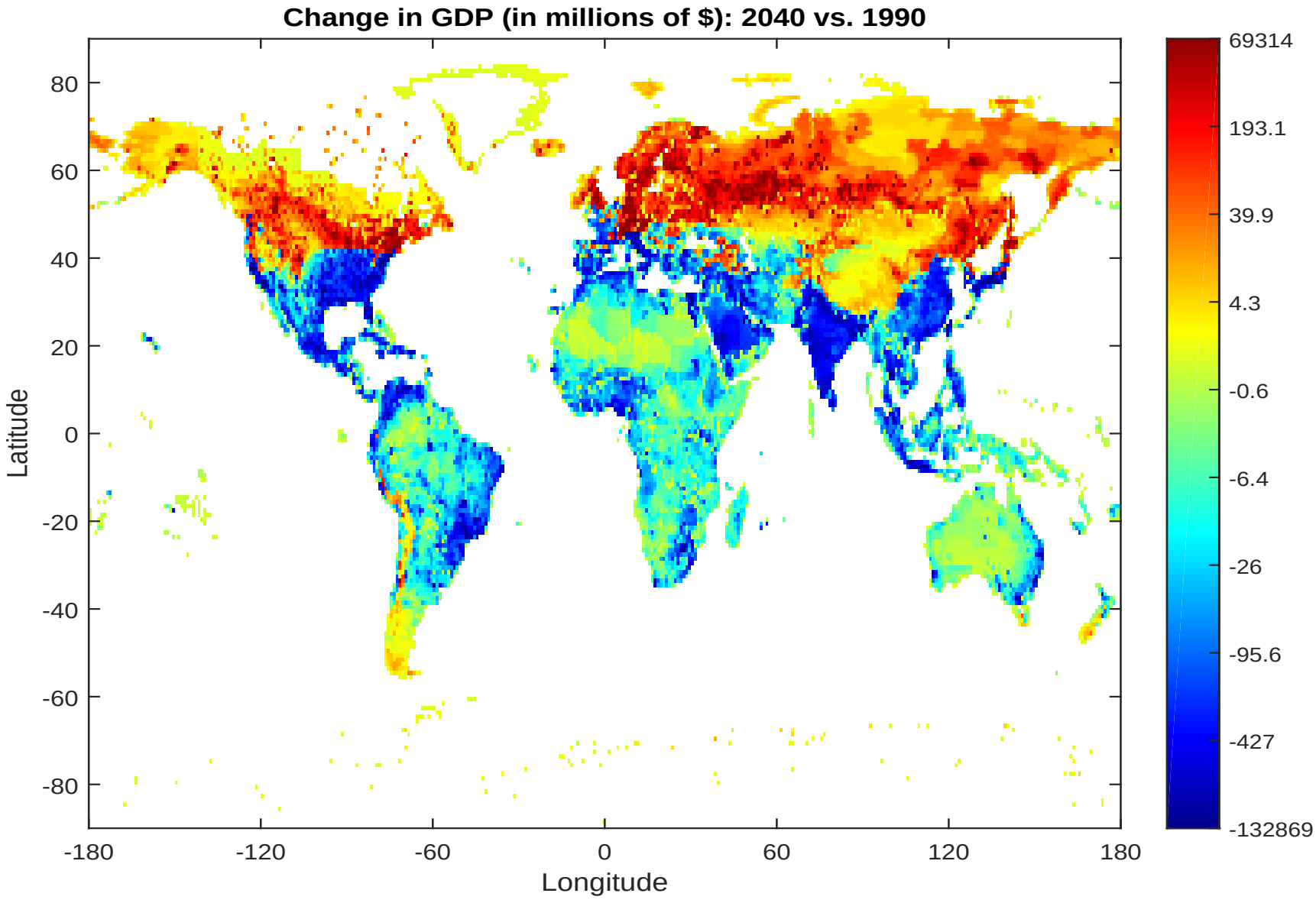
movie: level change in gdp, laissez-faire

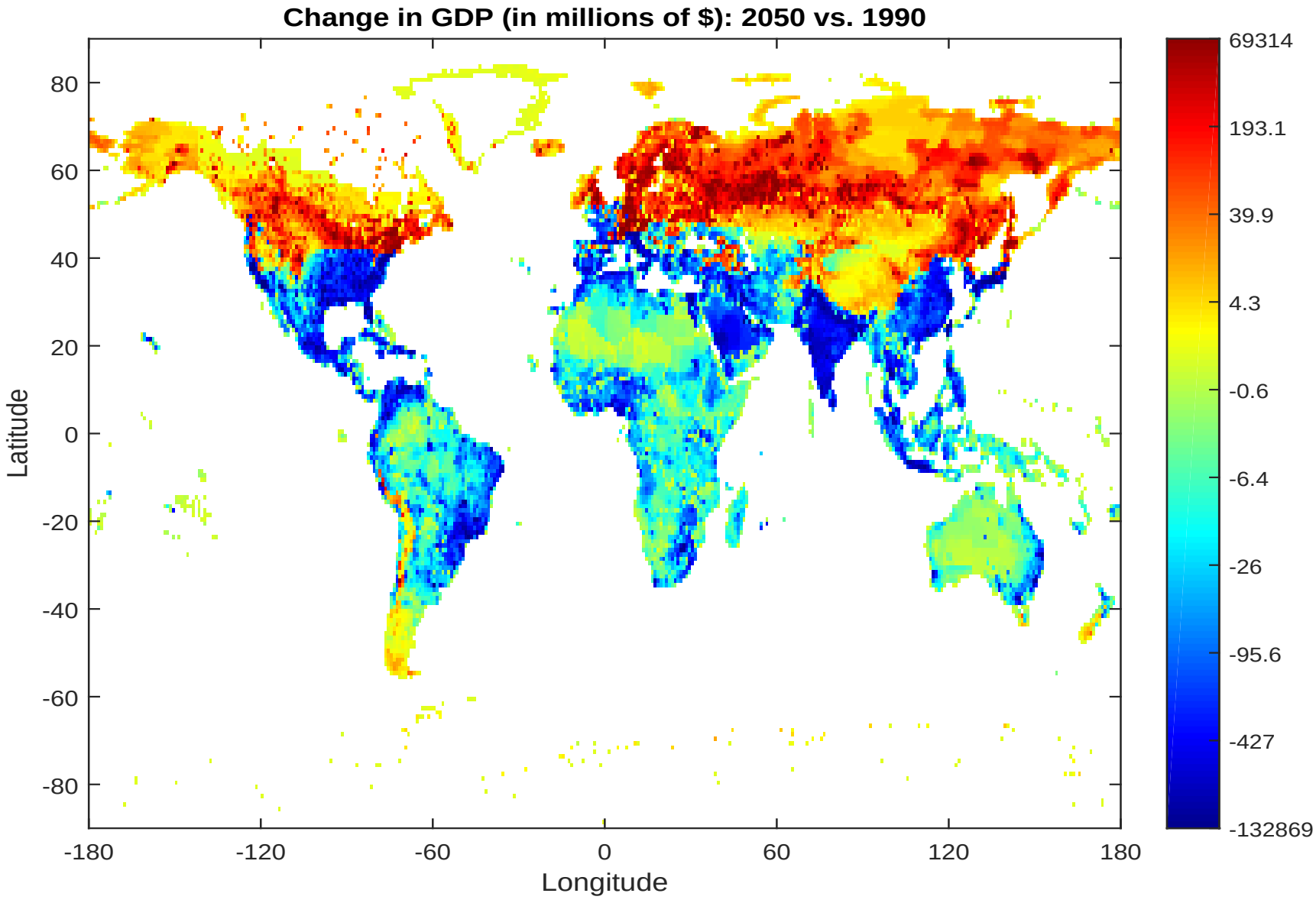

Change in GDP (in millions of $): 2000 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

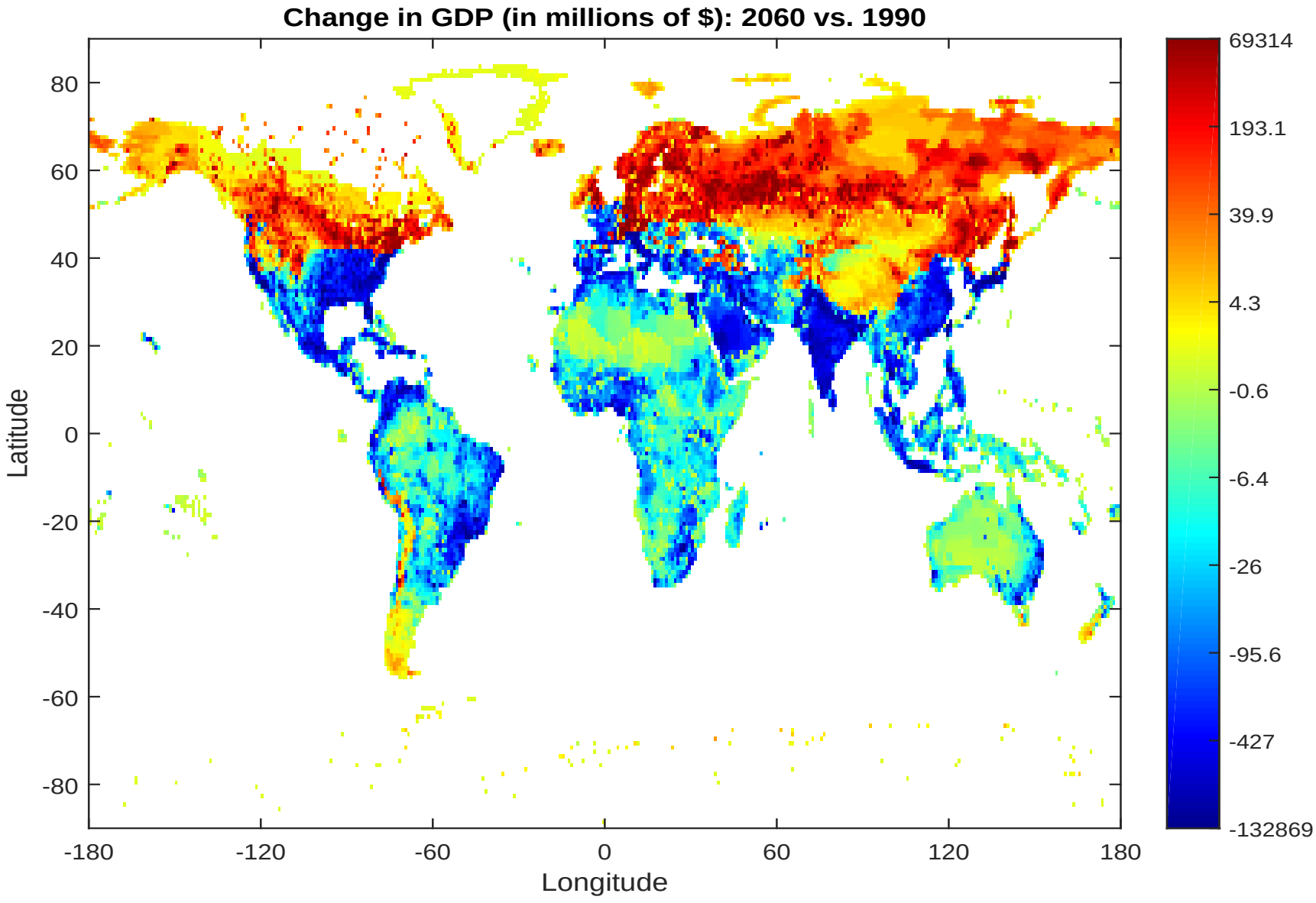

Change in GDP (in millions of $): 2010 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

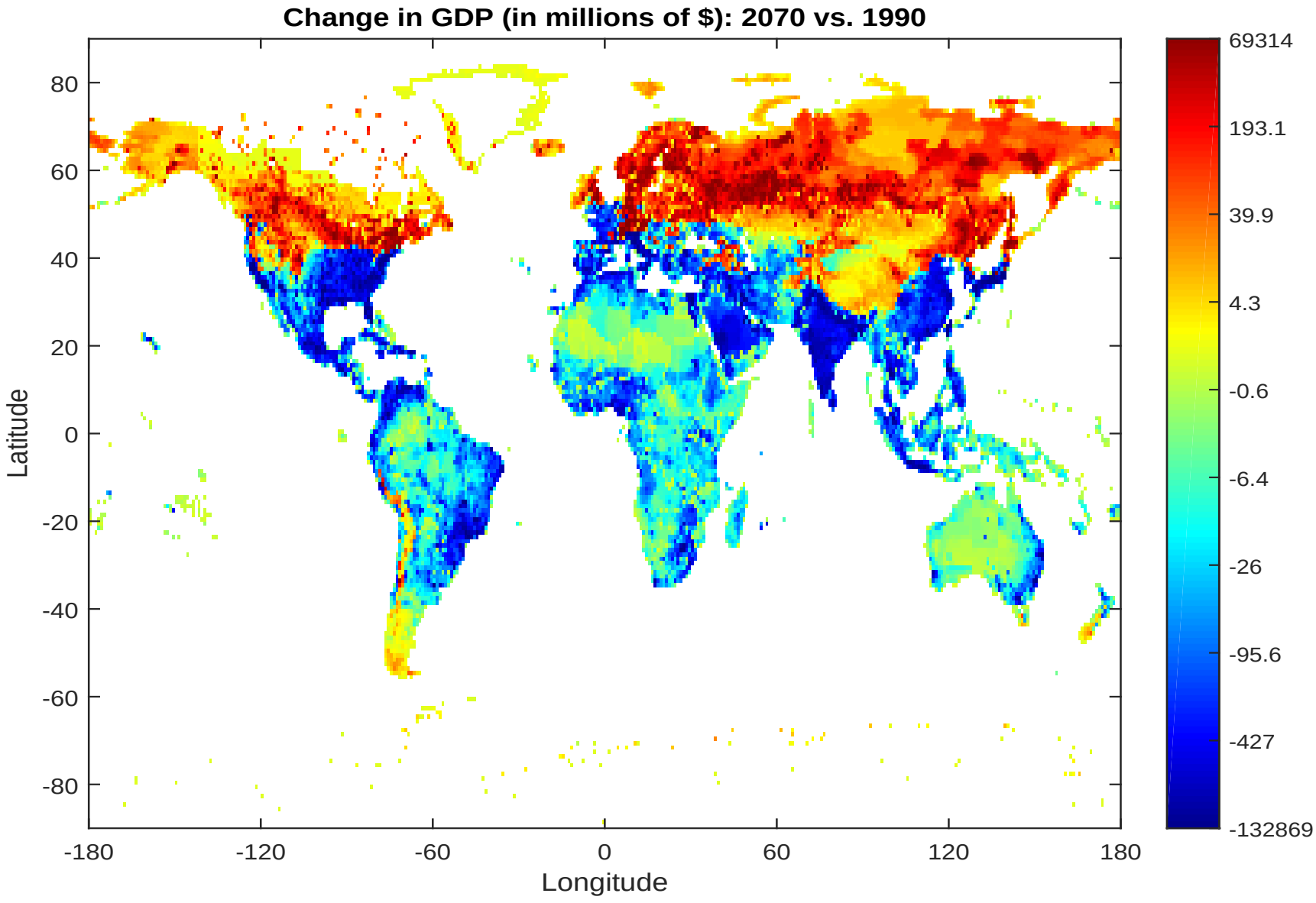

Change in GDP (in millions of $): 2020 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

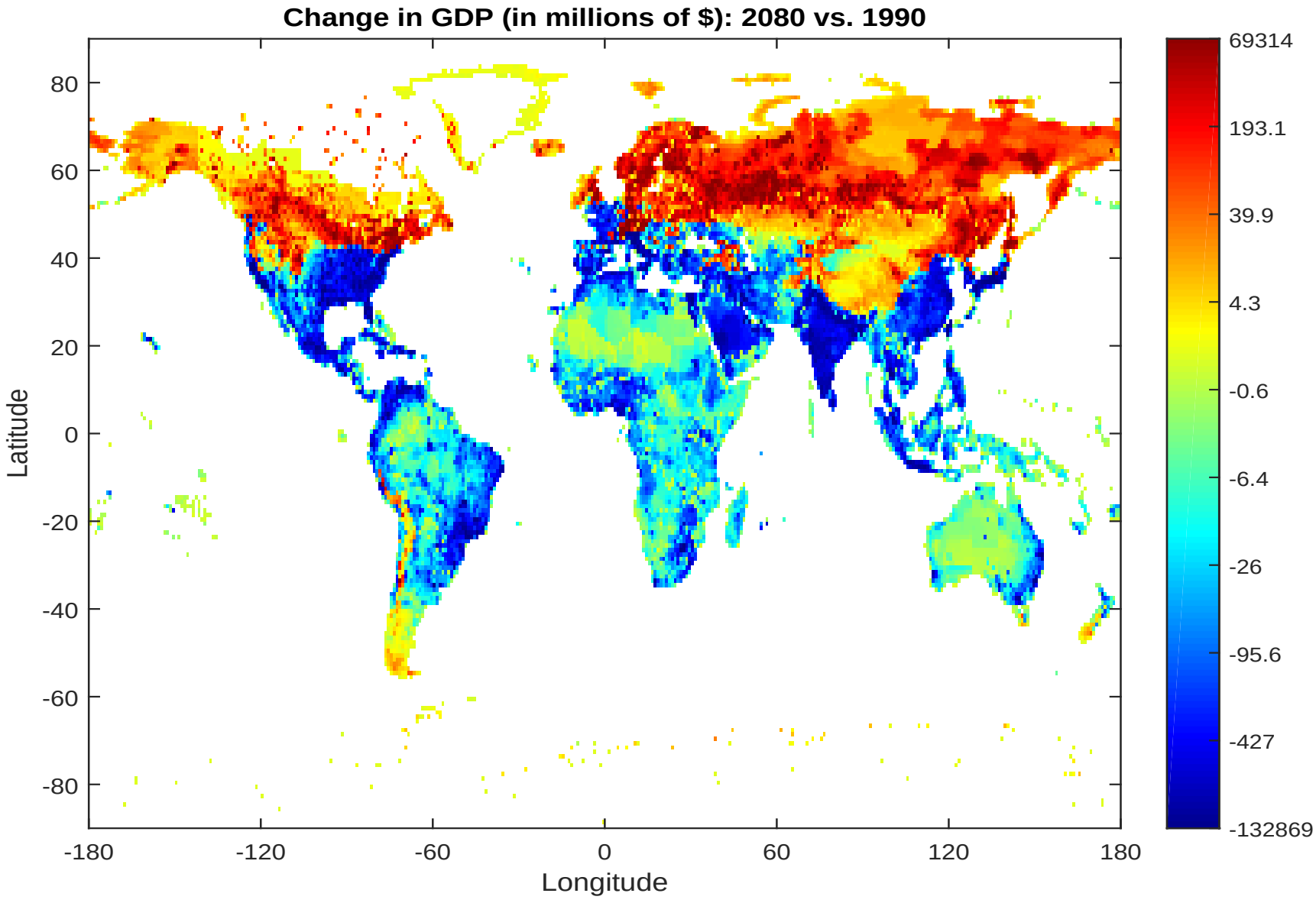

Change in GDP (in millions of $): 2030 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

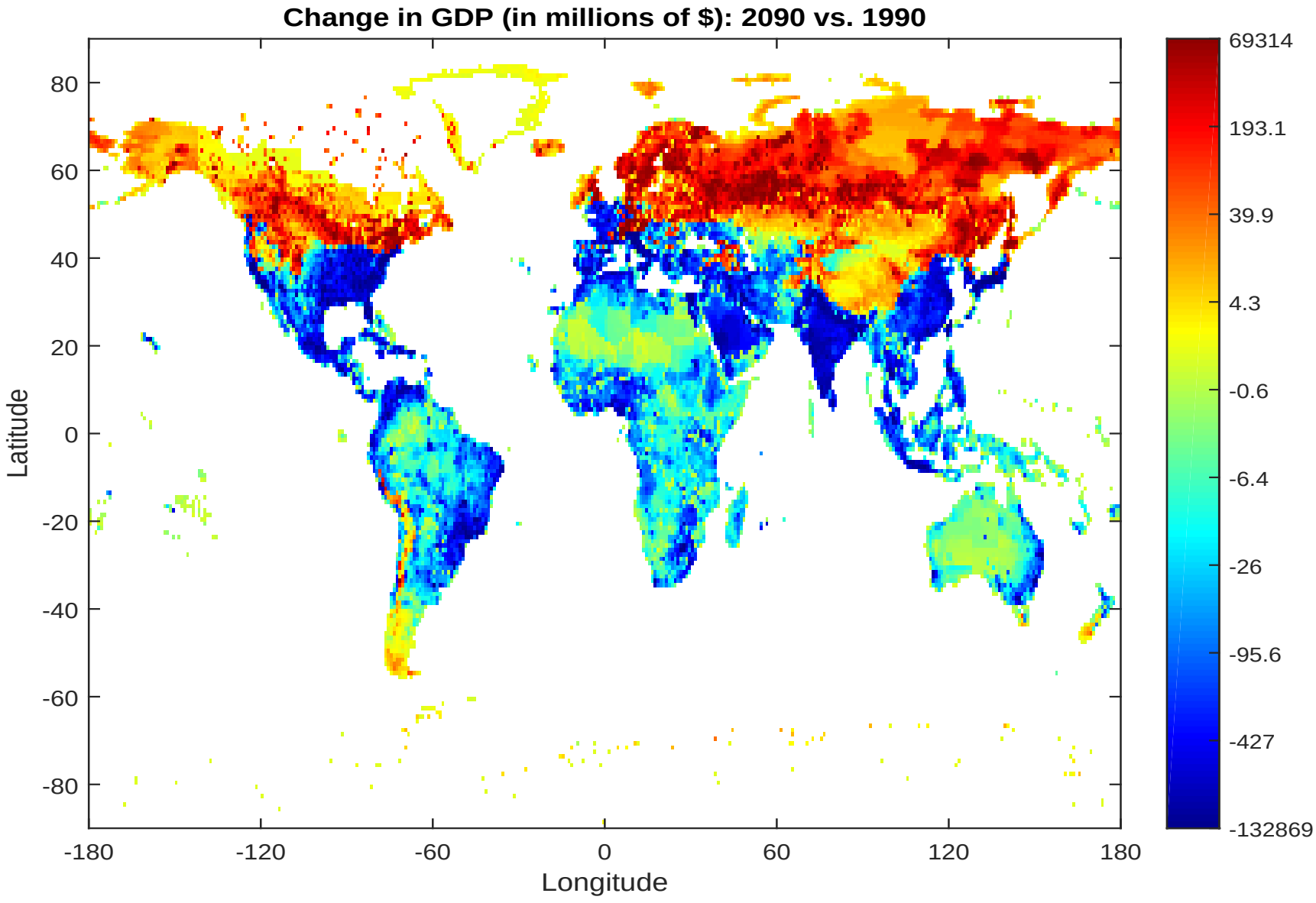

Change in GDP (in millions of $): 2040 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

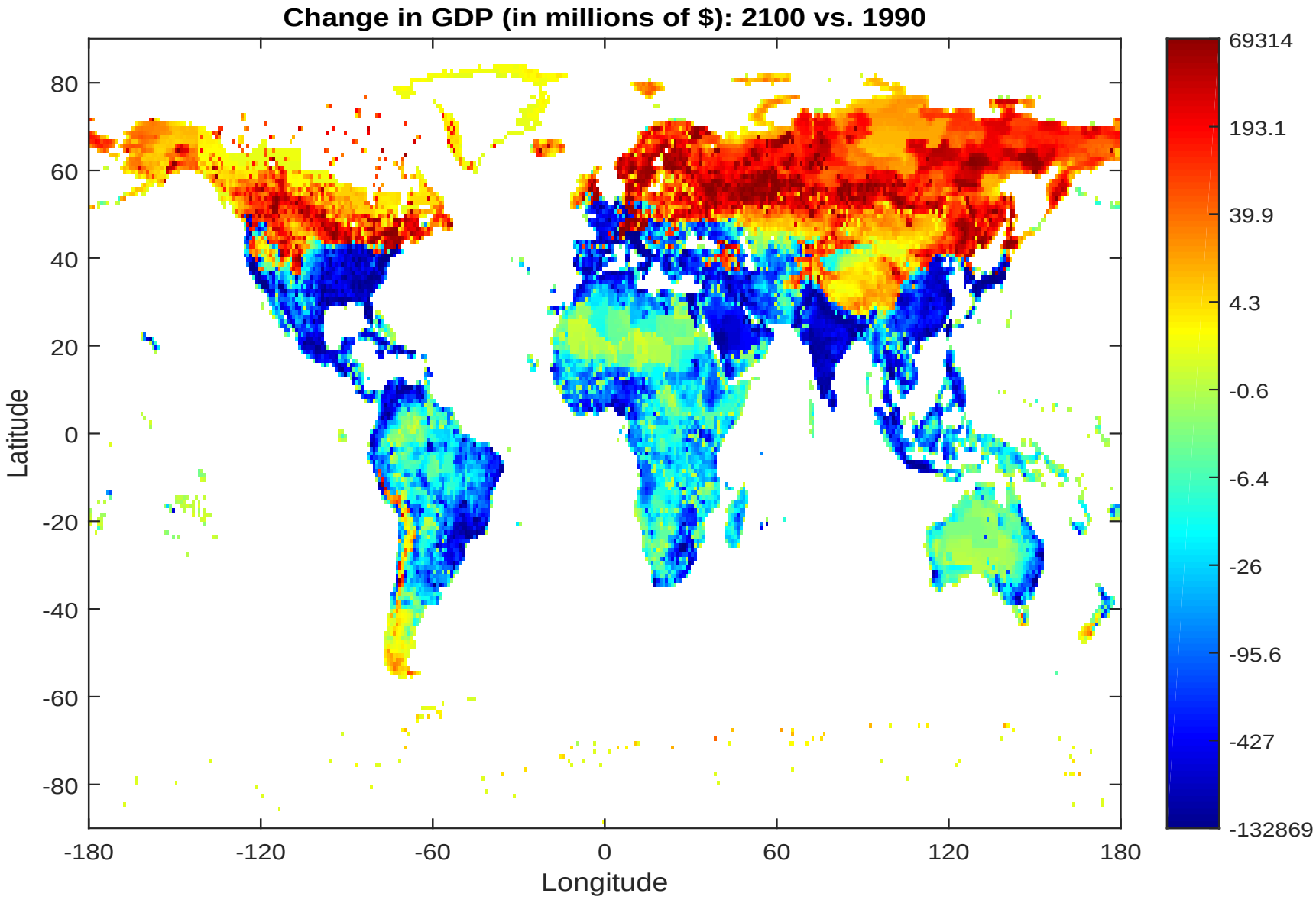

Change in GDP (in millions of $): 2050 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

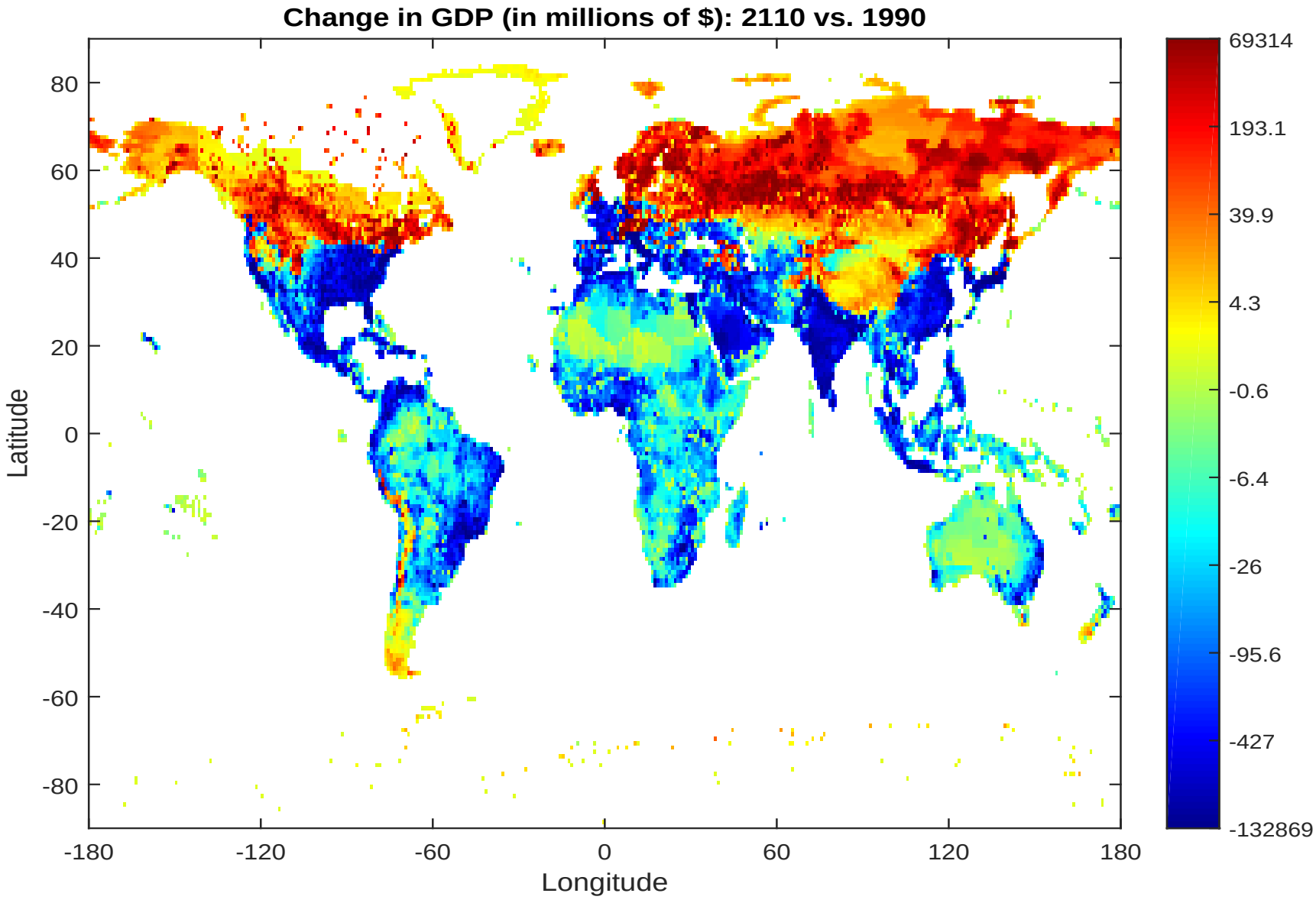

Change in GDP (in millions of $): 2060 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

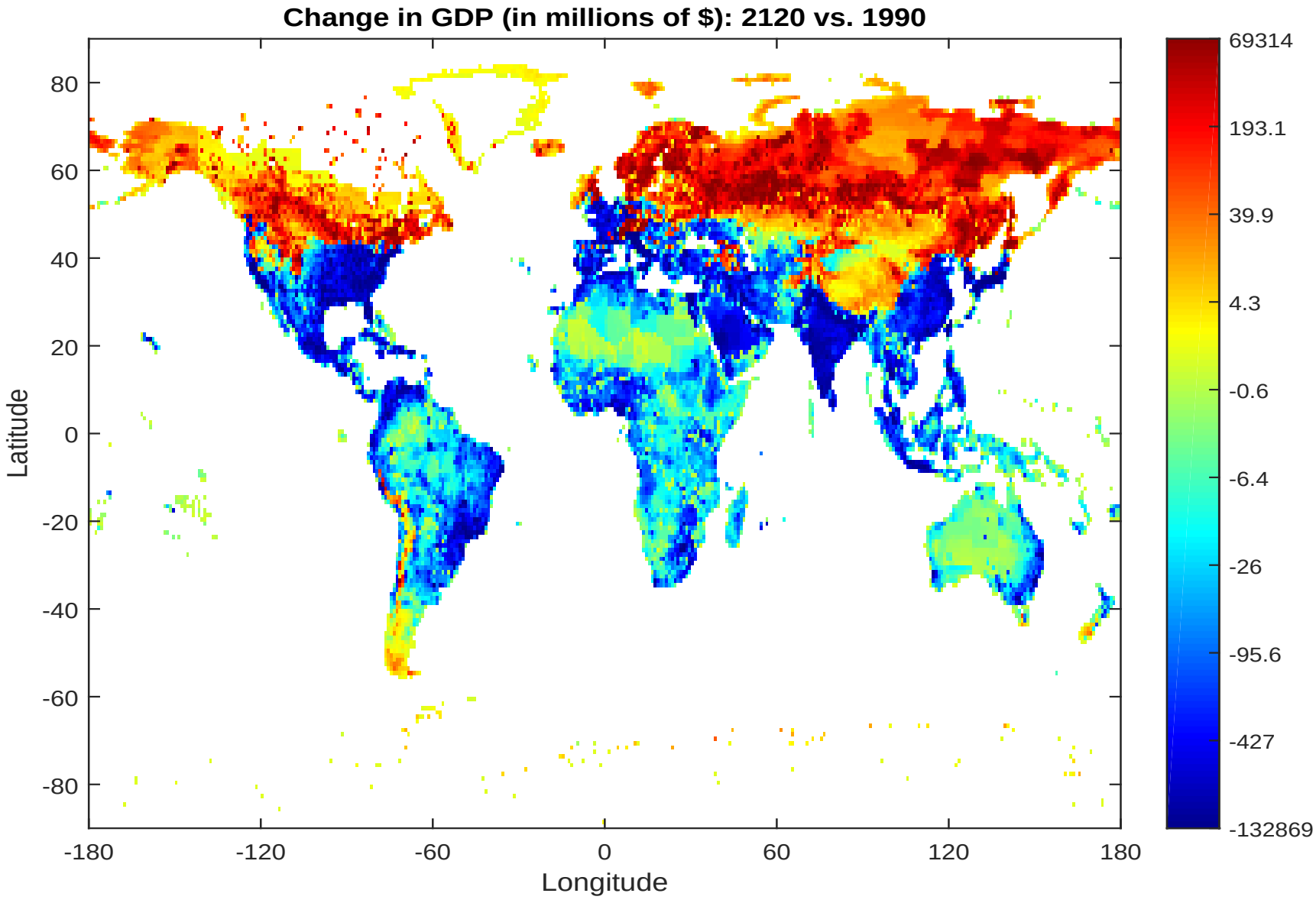

Change in GDP (in millions of $): 2070 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

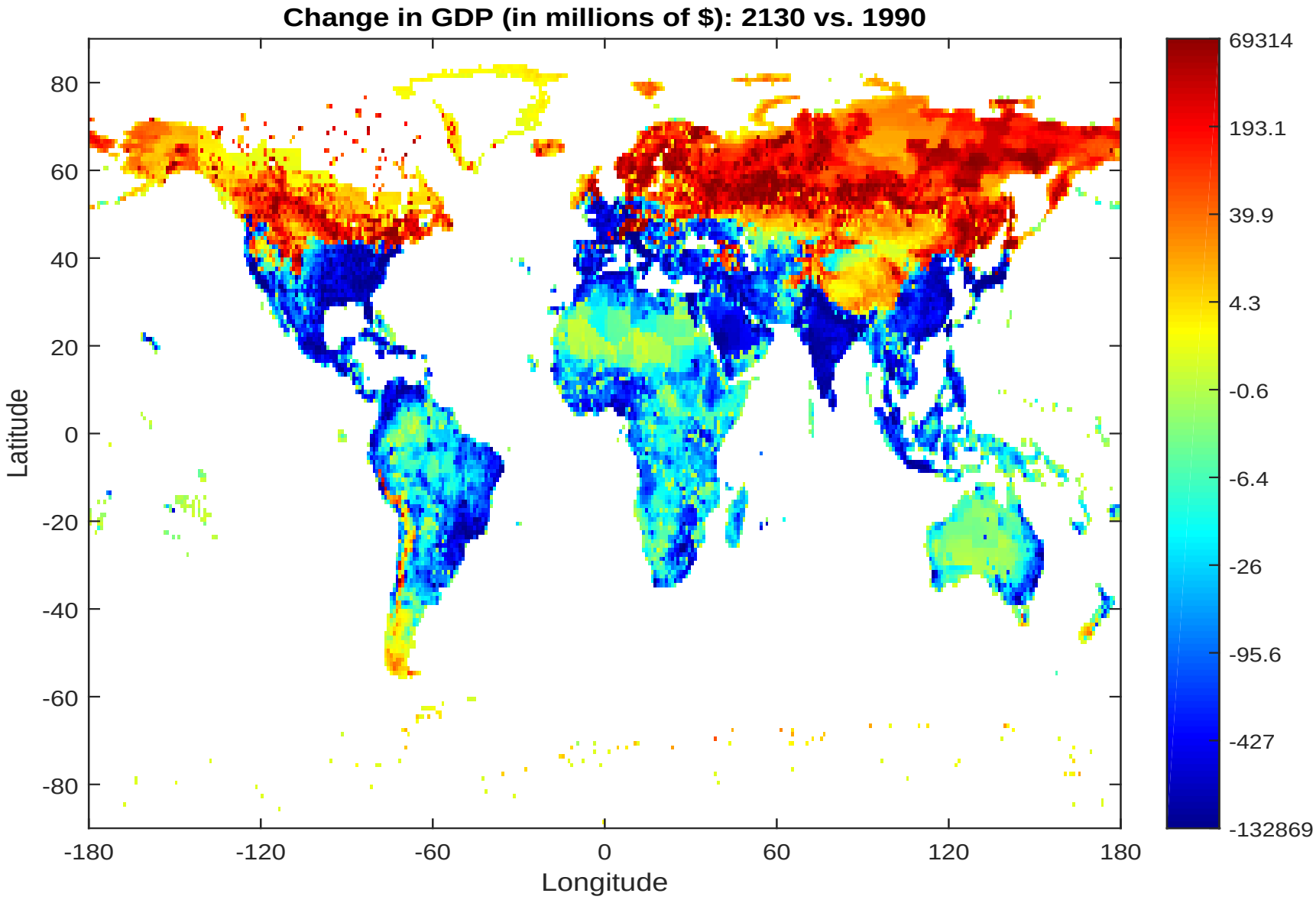

Change in GDP (in millions of $): 2080 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

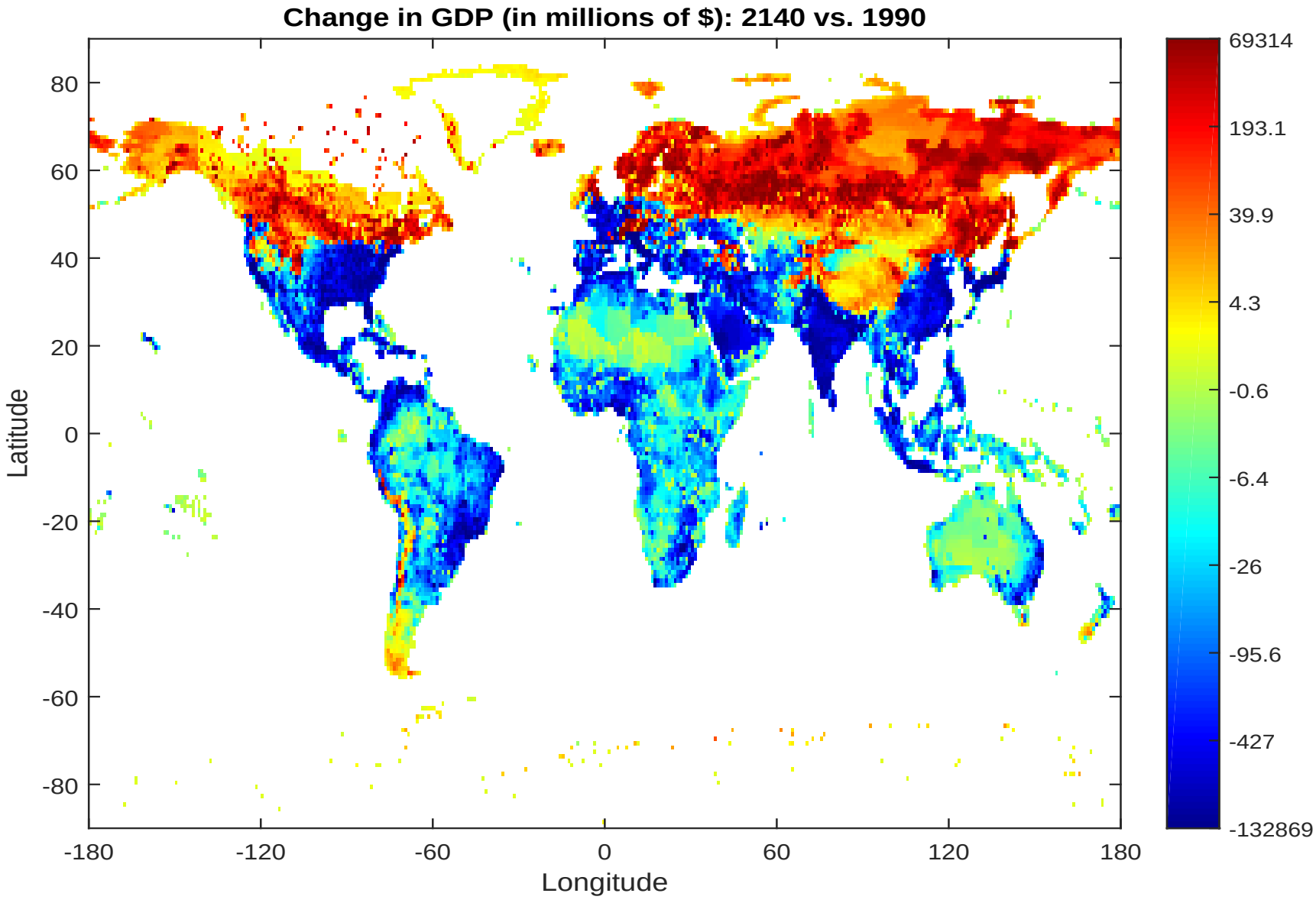

Change in GDP (in millions of $): 2090 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

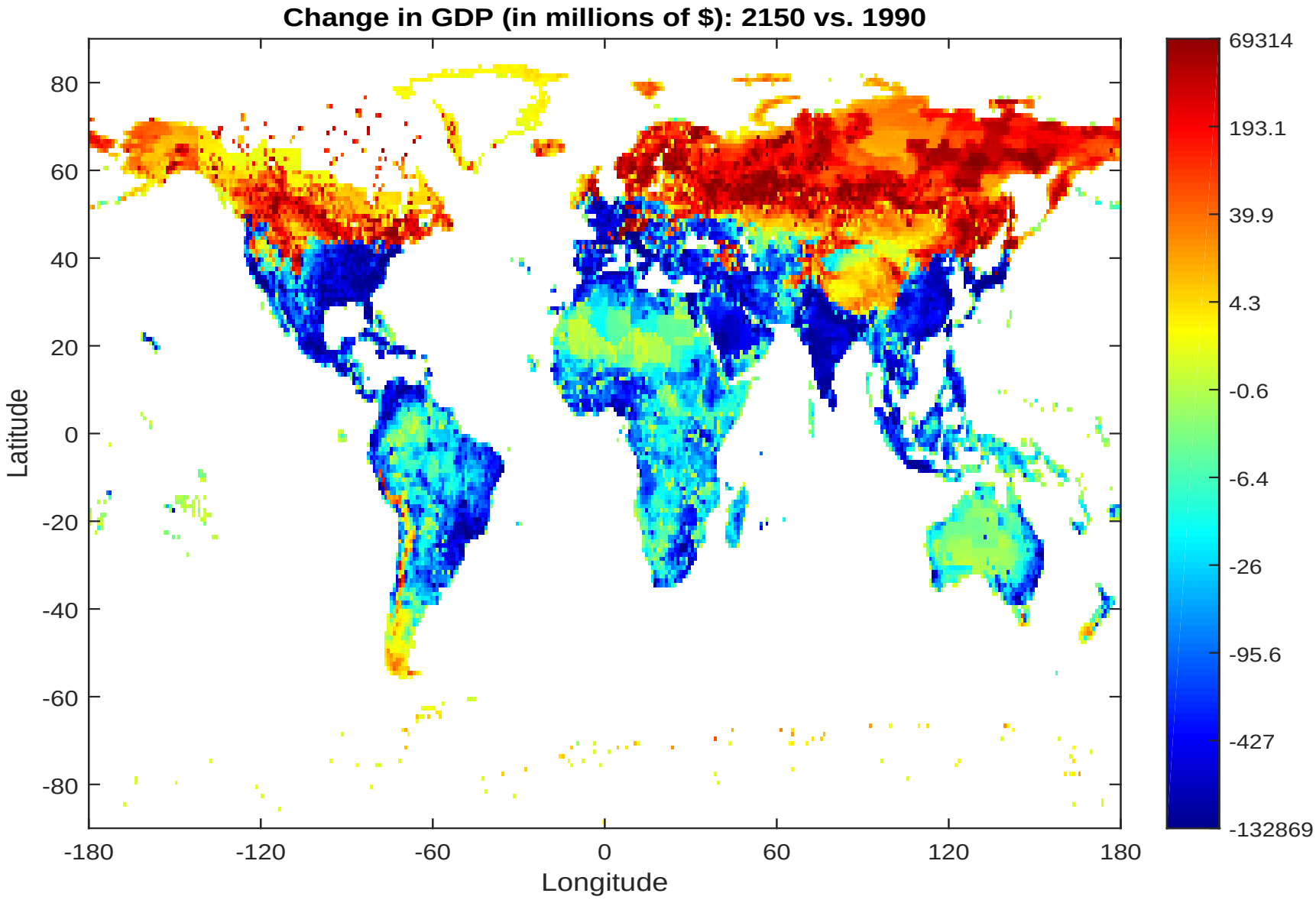

Change in GDP (in millions of $): 2100 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

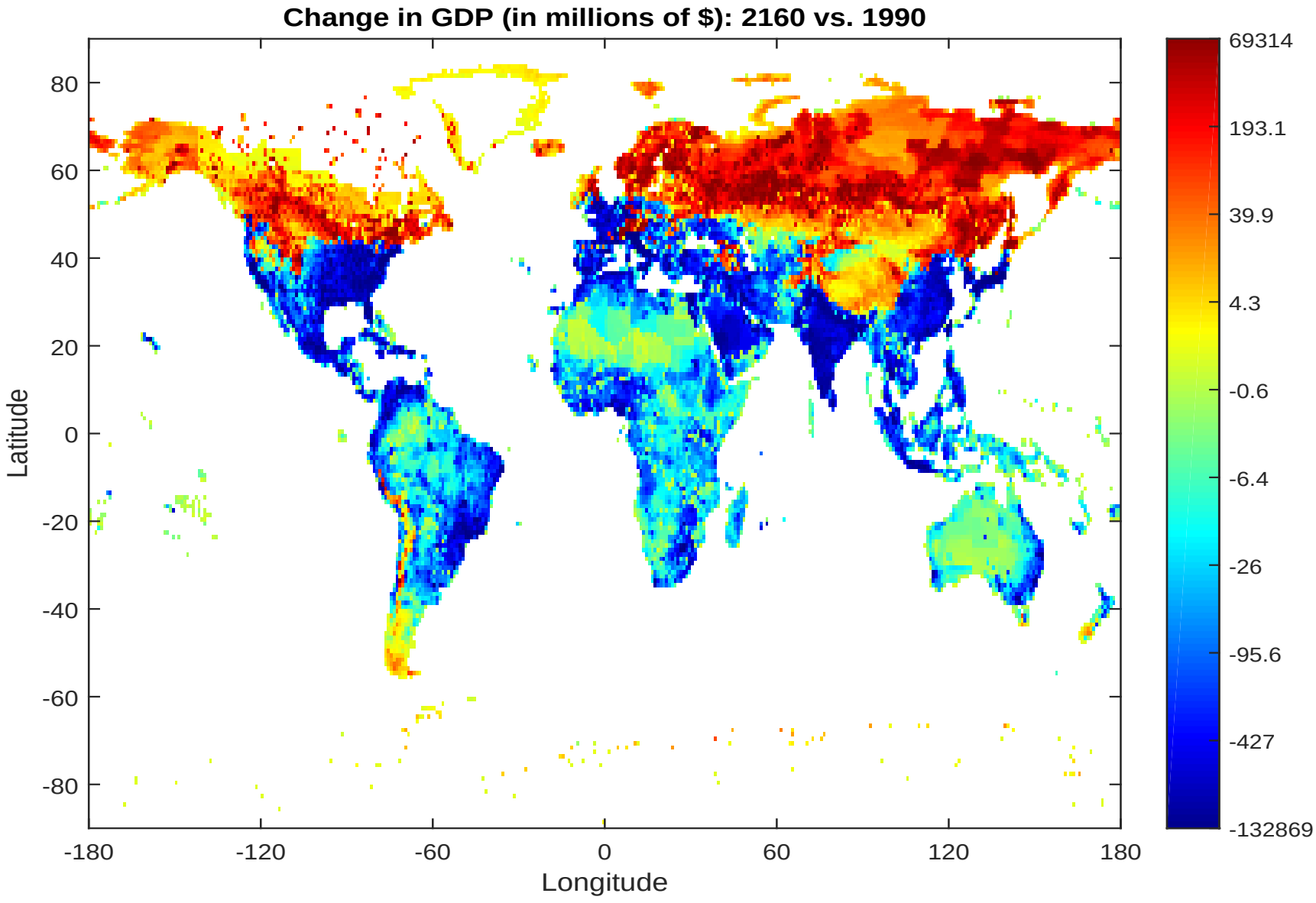

Change in GDP (in millions of $): 2110 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

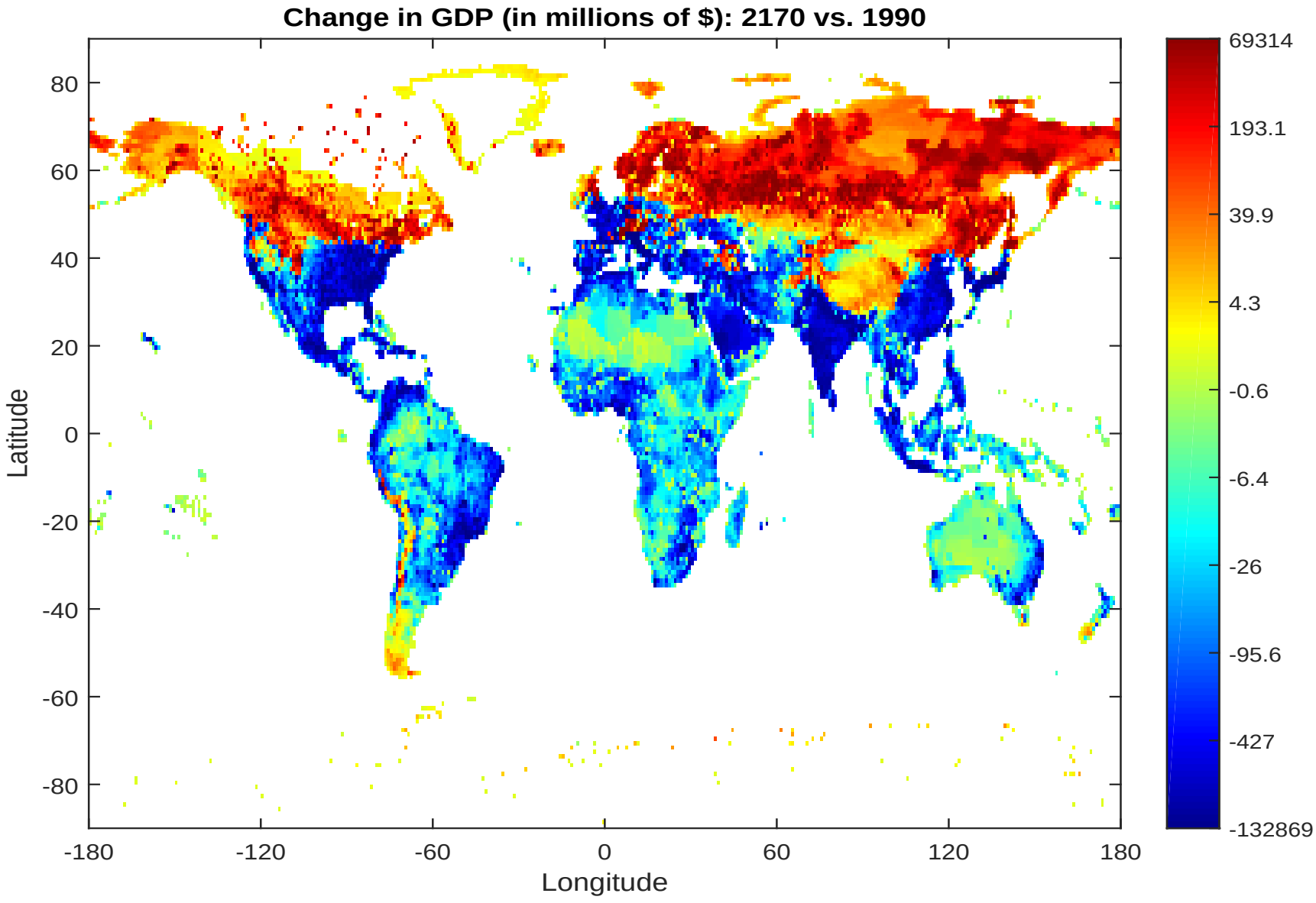

Change in GDP (in millions of $): 2120 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

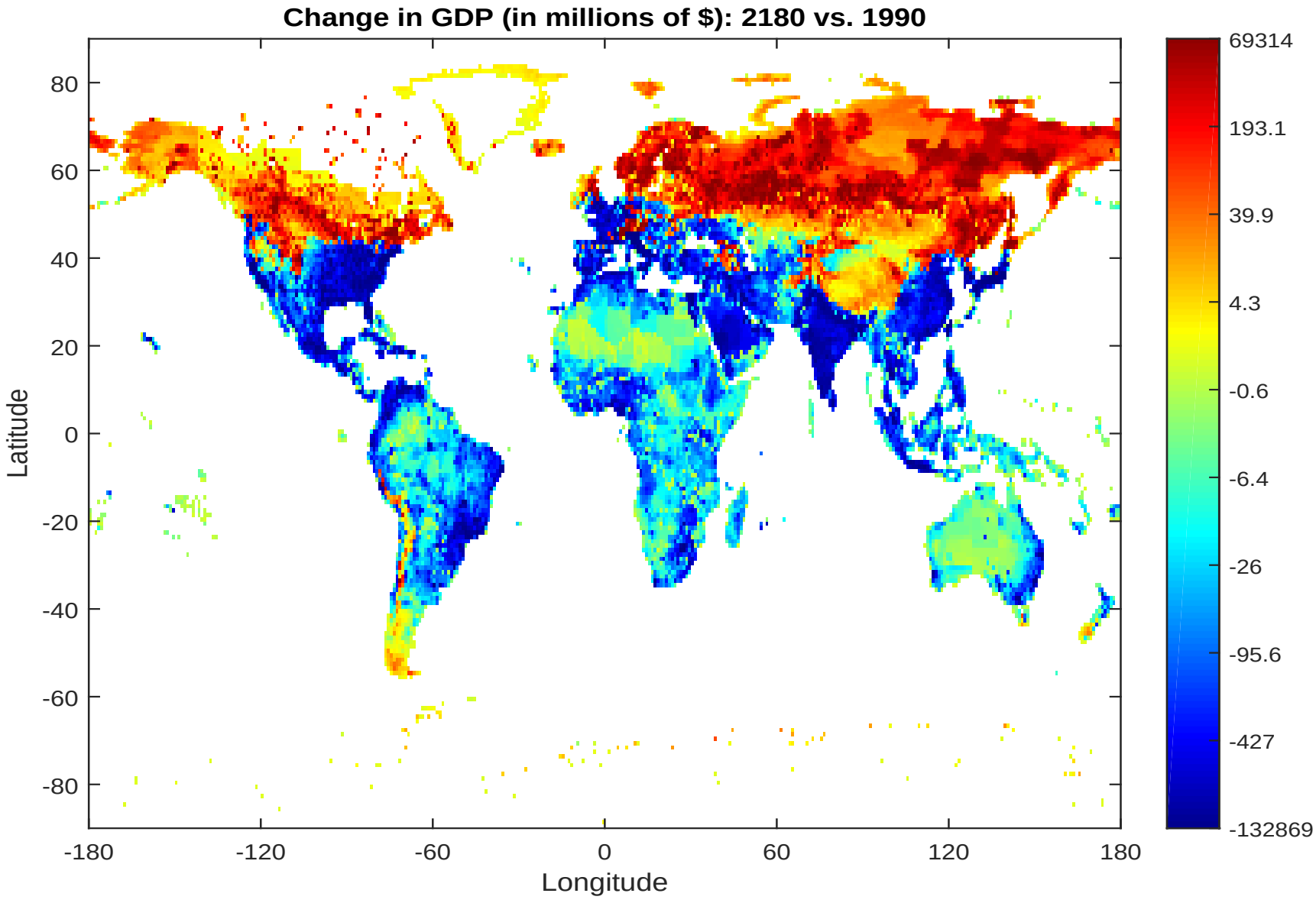

Change in GDP (in millions of $): 2130 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

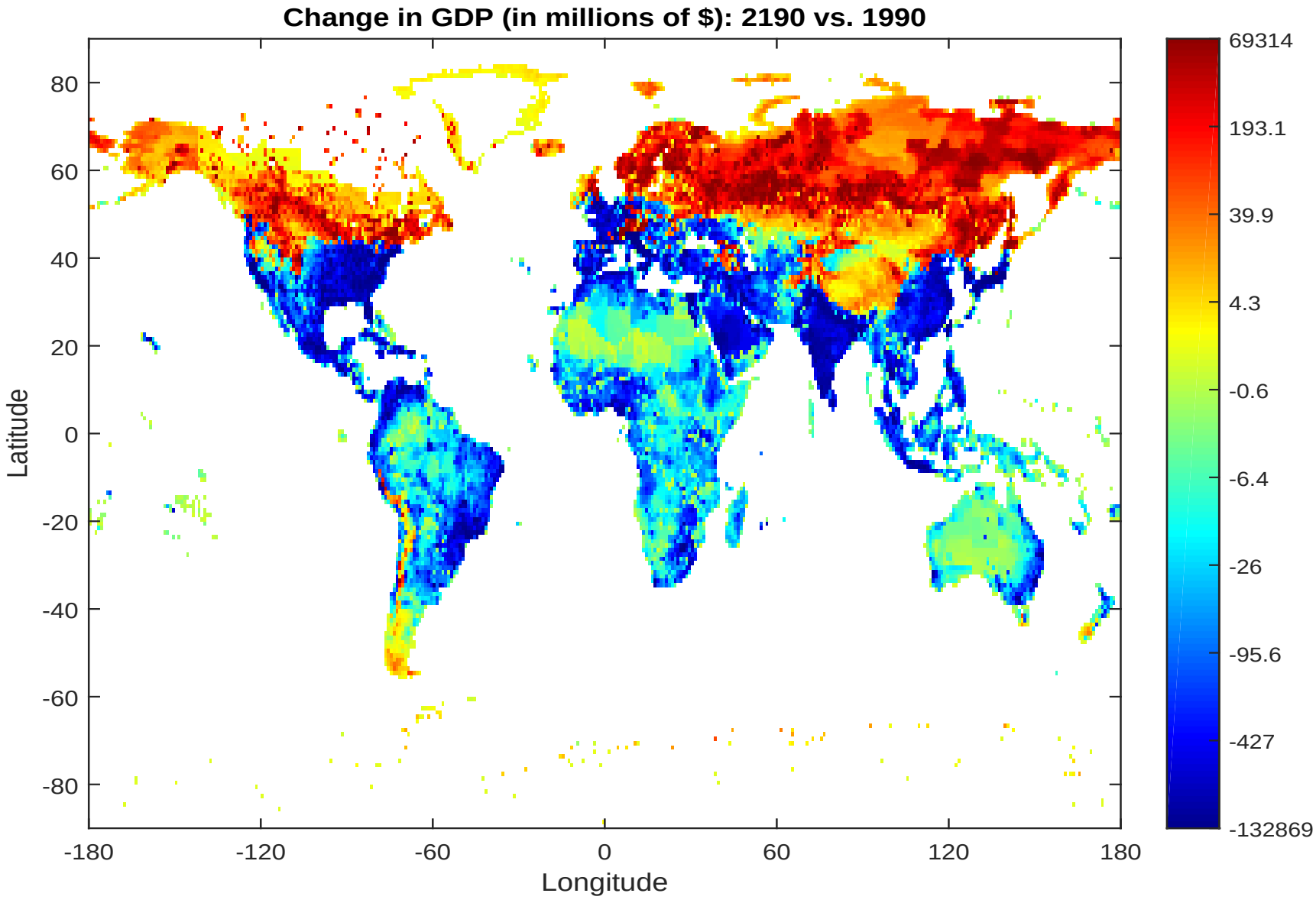

Change in GDP (in millions of $): 2140 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

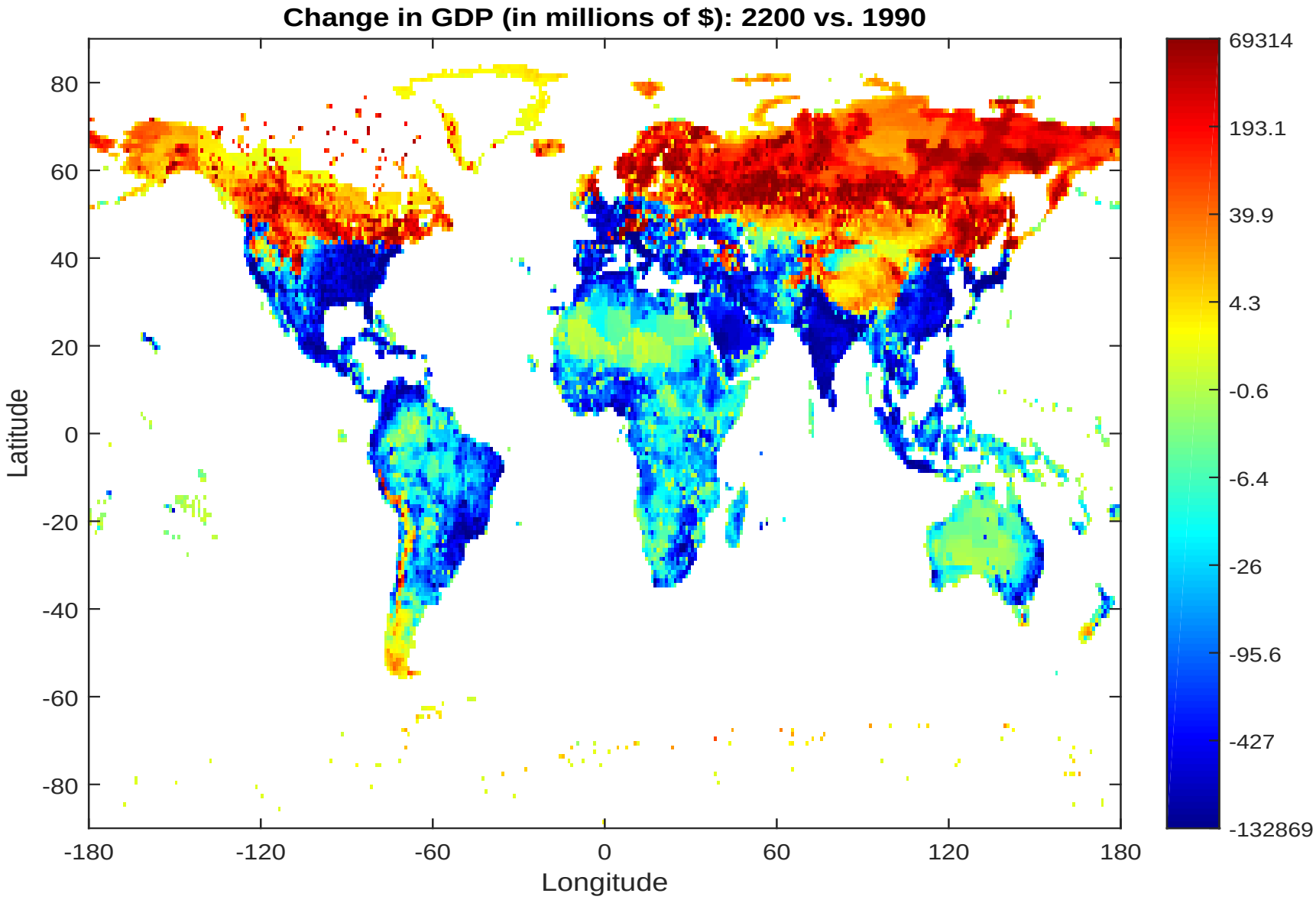

Change in GDP (in millions of $): 2150 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869


Change in GDP (in millions of $): 2160 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

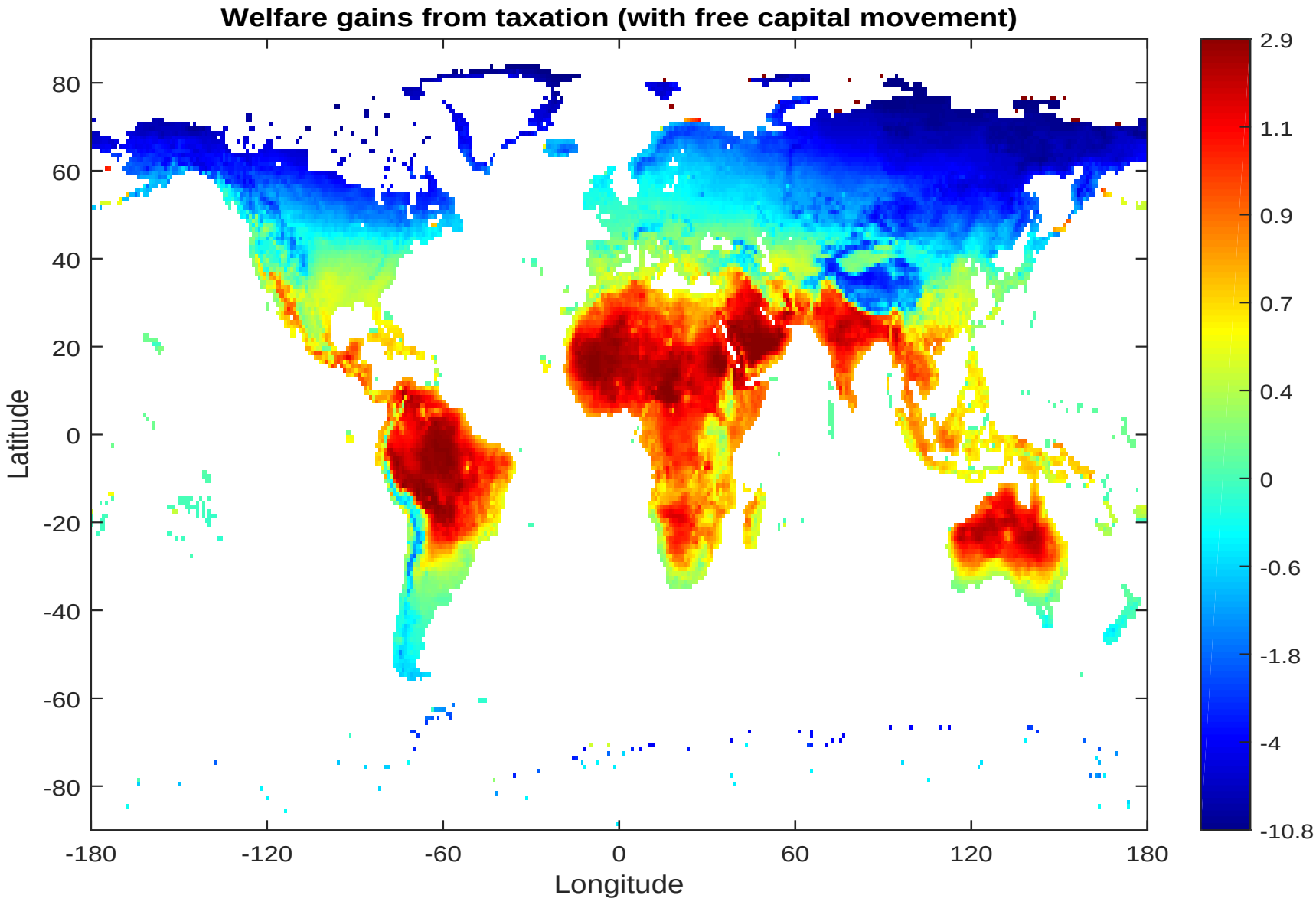

Change in GDP (in millions of $): 2170 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

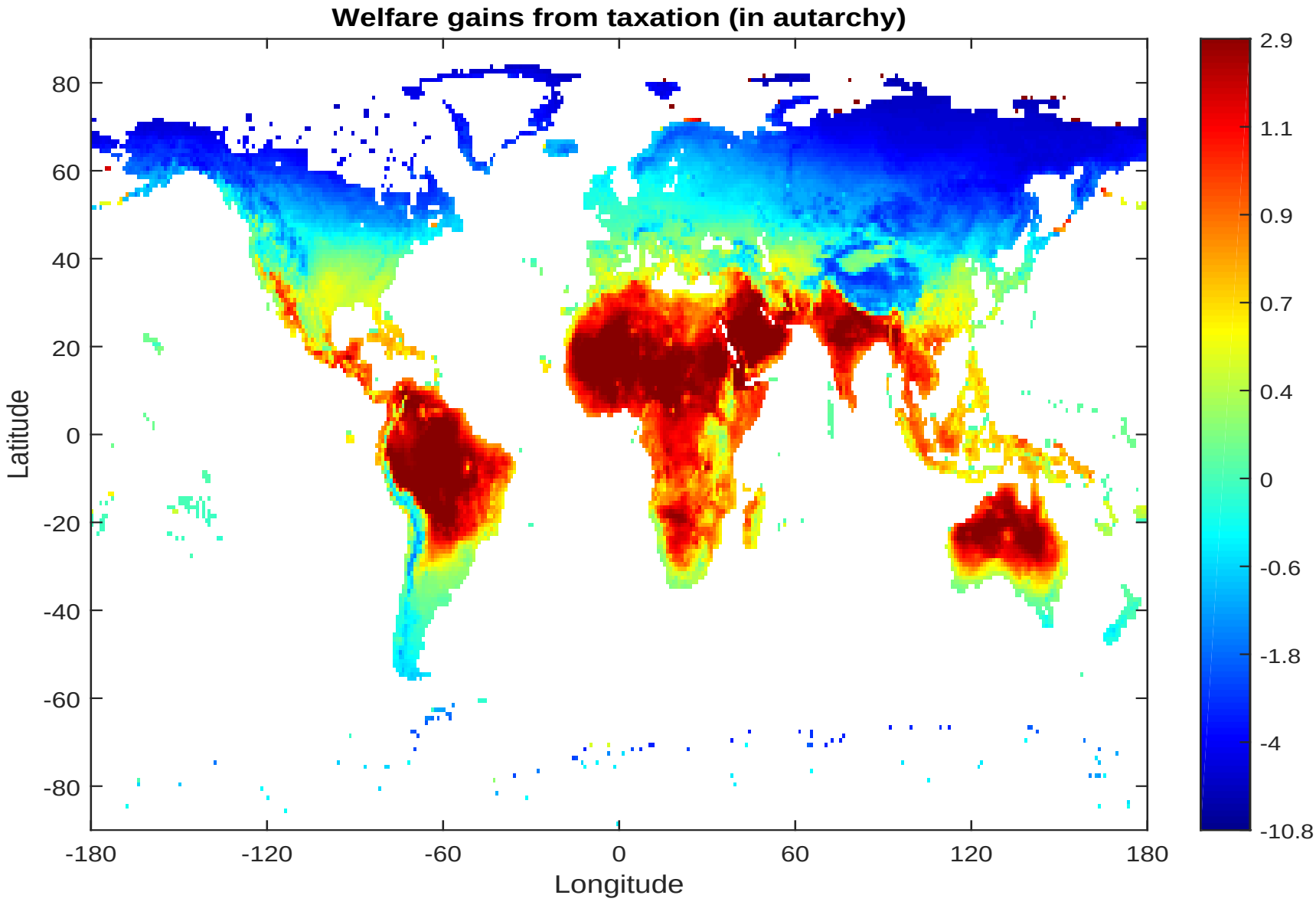

Change in GDP (in millions of $): 2180 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869


Change in GDP (in millions of $): 2190 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

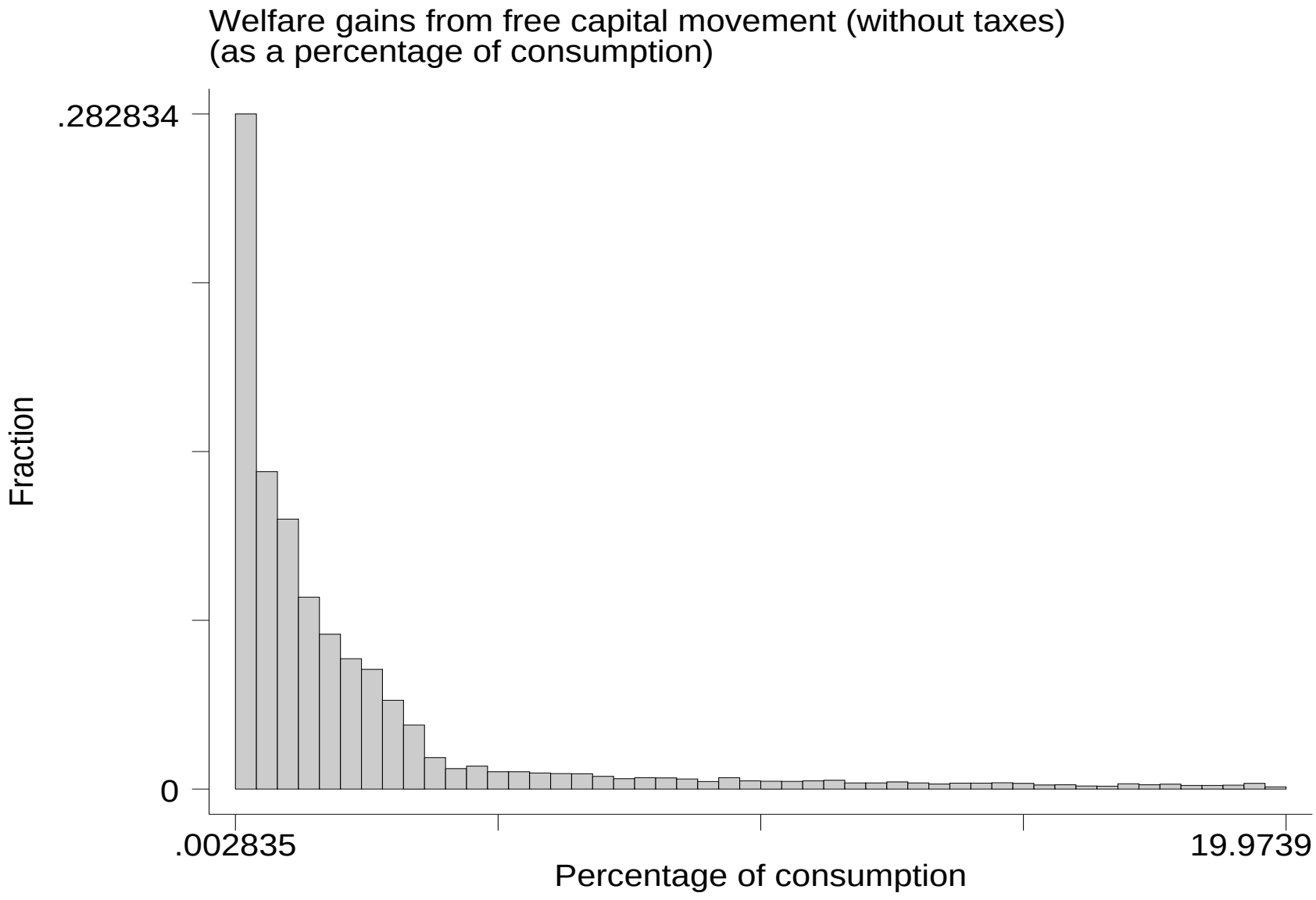

Change in GDP (in millions of $): 2200 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

pictures: map of winners and losers from tax, full equalization (then autarky)

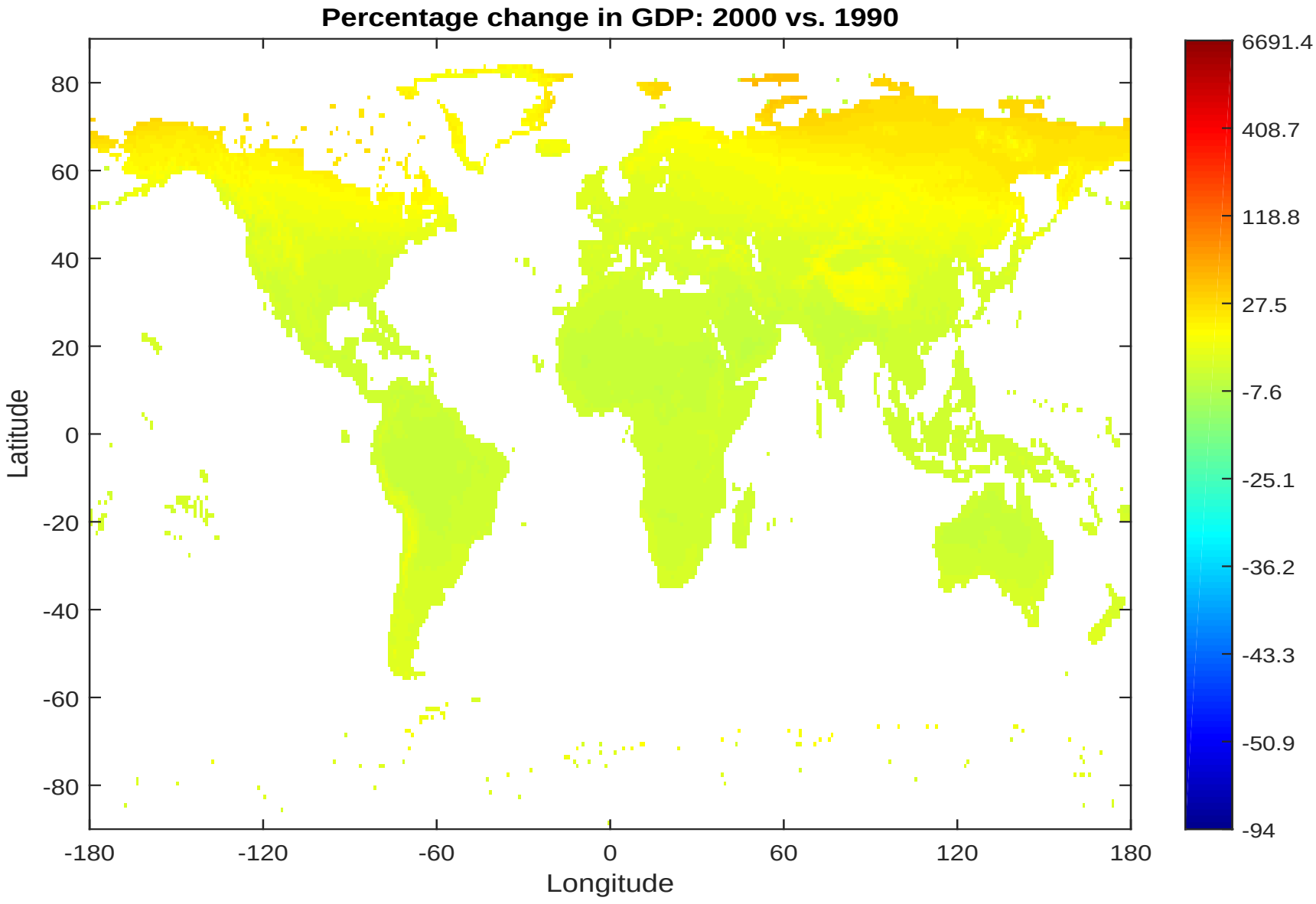

Welfare gains from taxation (with free capital movement)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
2.9
1.1
0.9
0.7
0.4
0
-0.6
-1.8
-4
-10.8

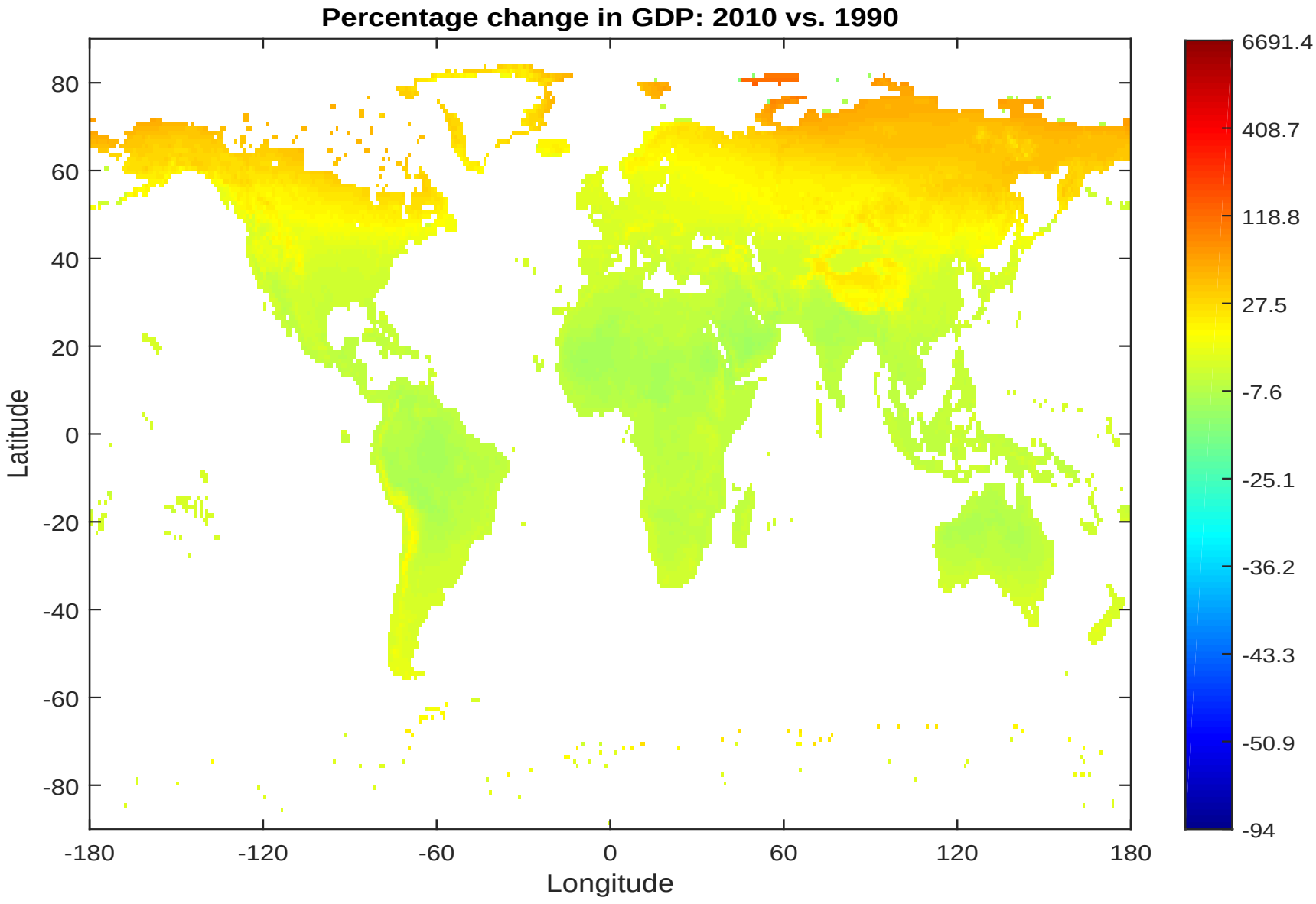

Welfare gains from taxation (in autarchy)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
2.9
1.1
0.9
0.7
0.4
0
-0.6
-1.8
-4
-10.8

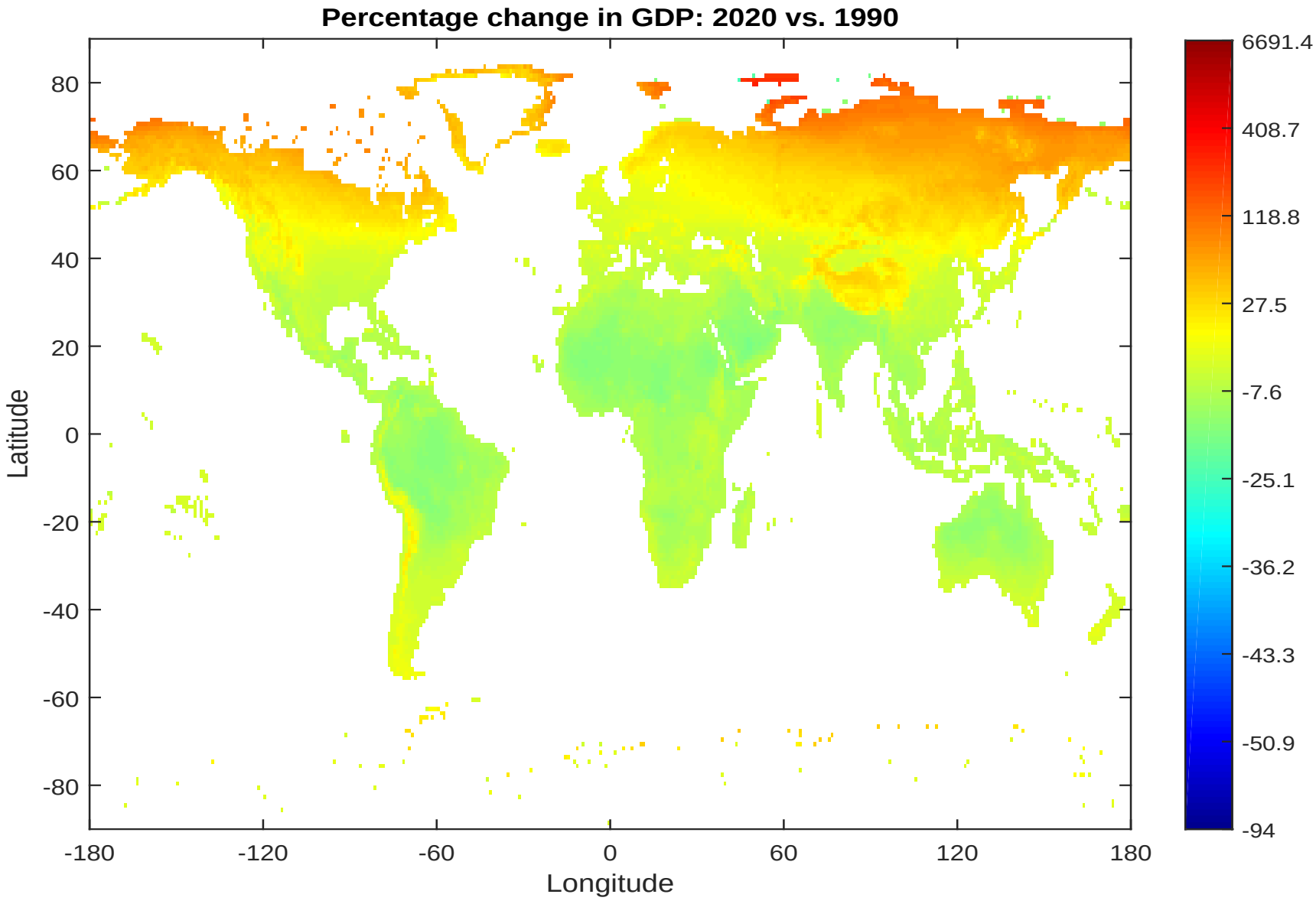
picture: welfare gains from free capital movements (laissez-faire)

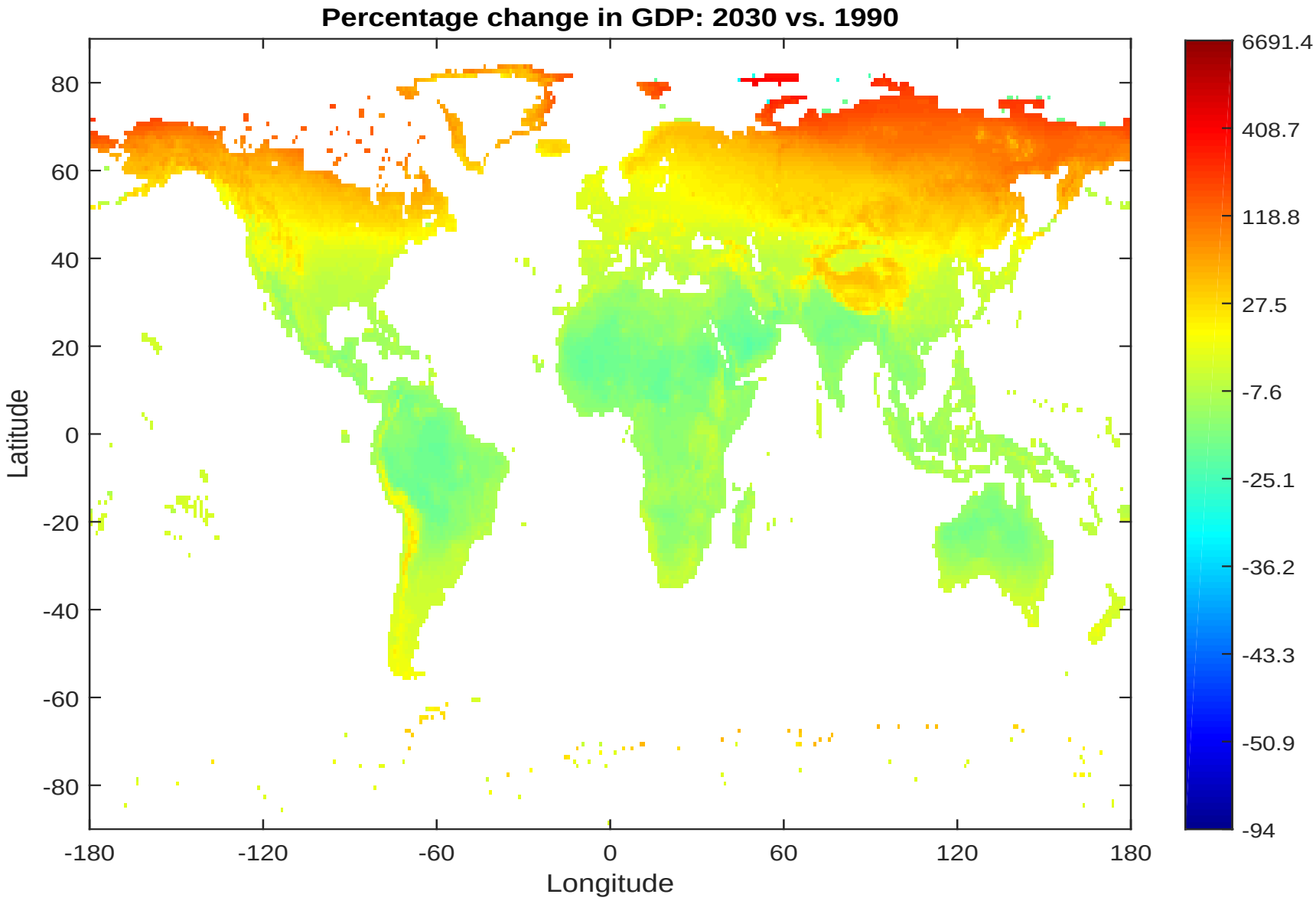

Welfare gains from free capital movement (without taxes)
(as a percentage of consumption)
.282834
0
Fraction
.002835
19.9739
Percentage of consumption

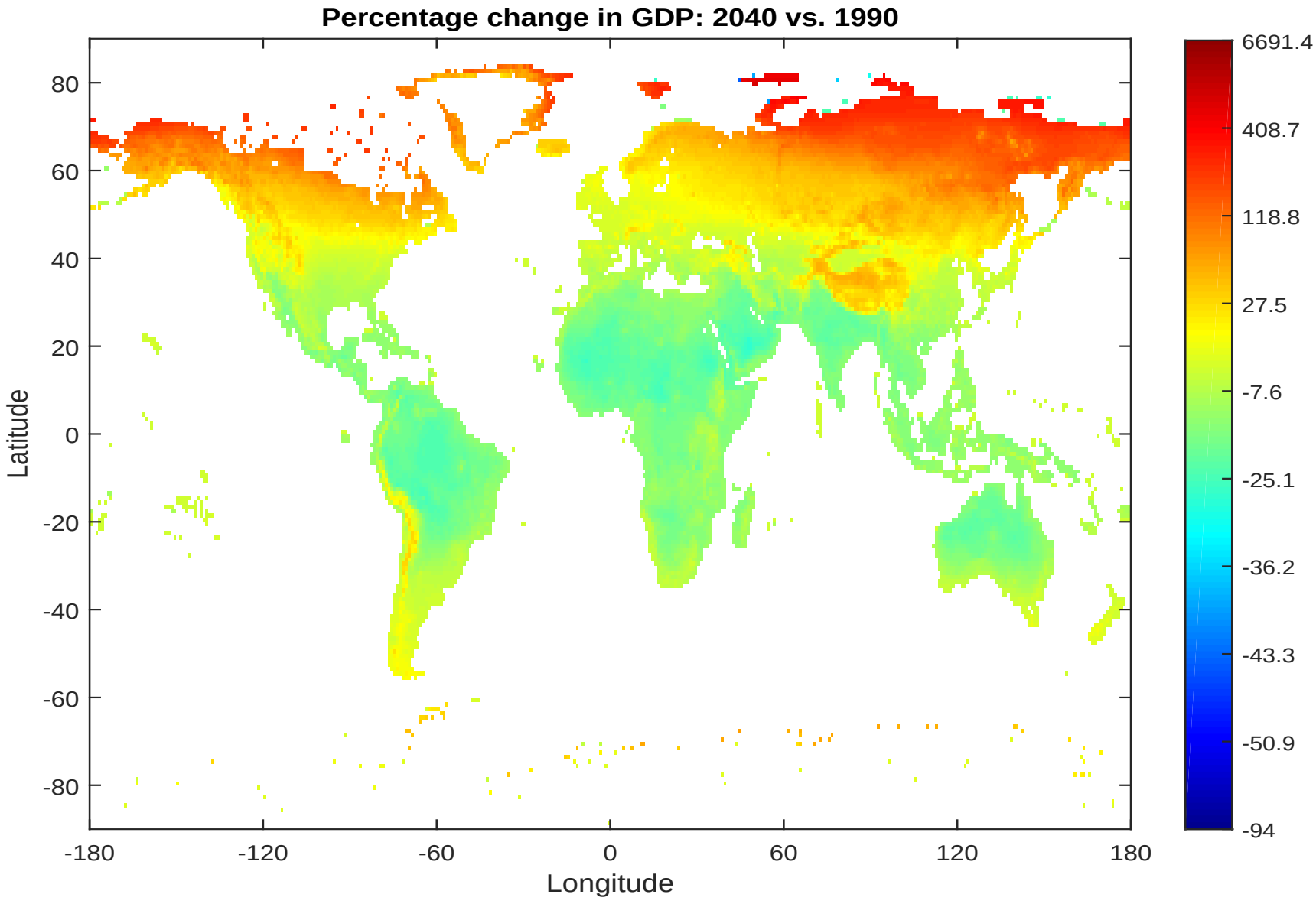
movie: percentage change in gdp, taxes

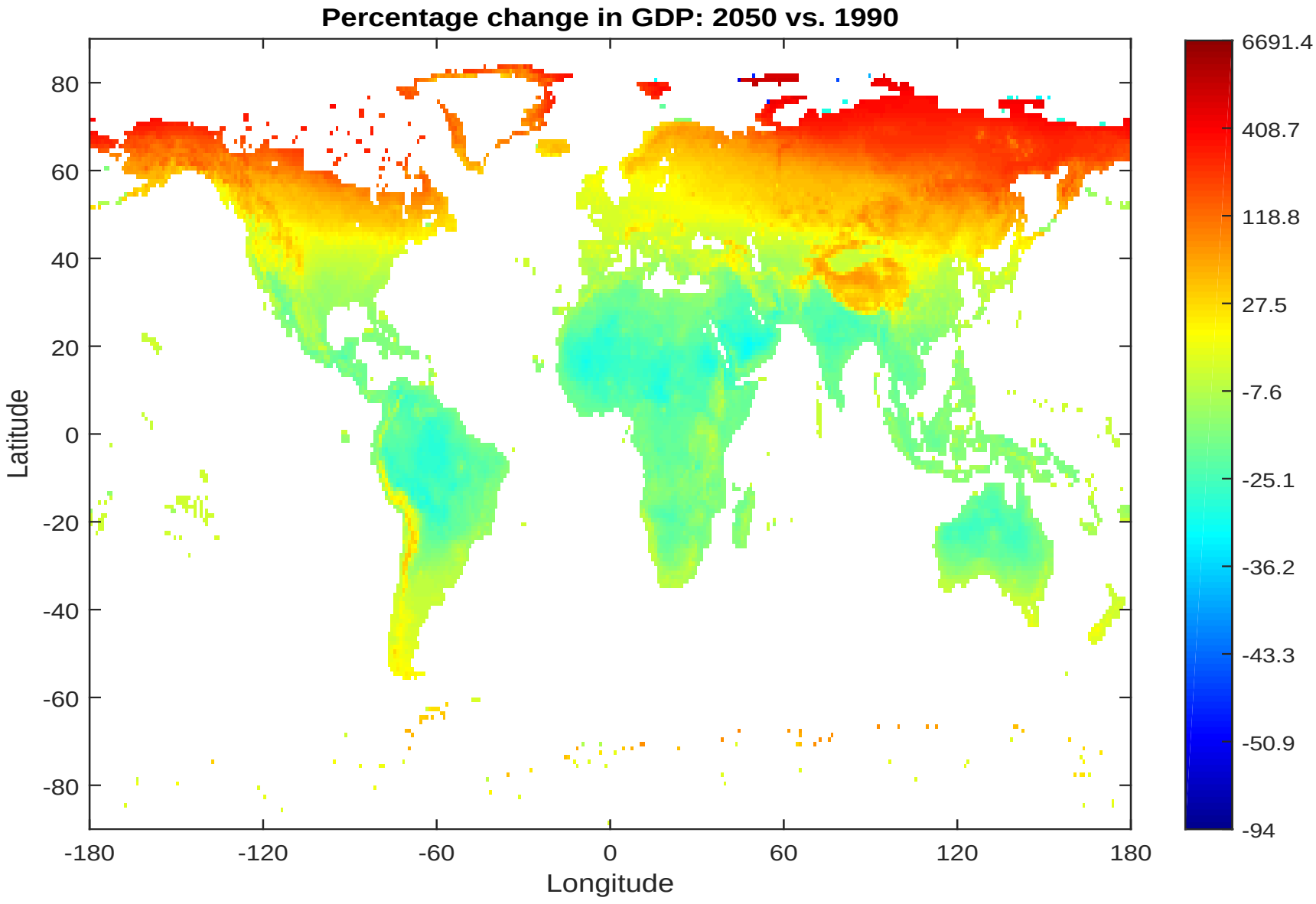

Percentage change in GDP: 2000 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2010 vs. 1990
Latitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
Longitude
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2020 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2030 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2040 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2050 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
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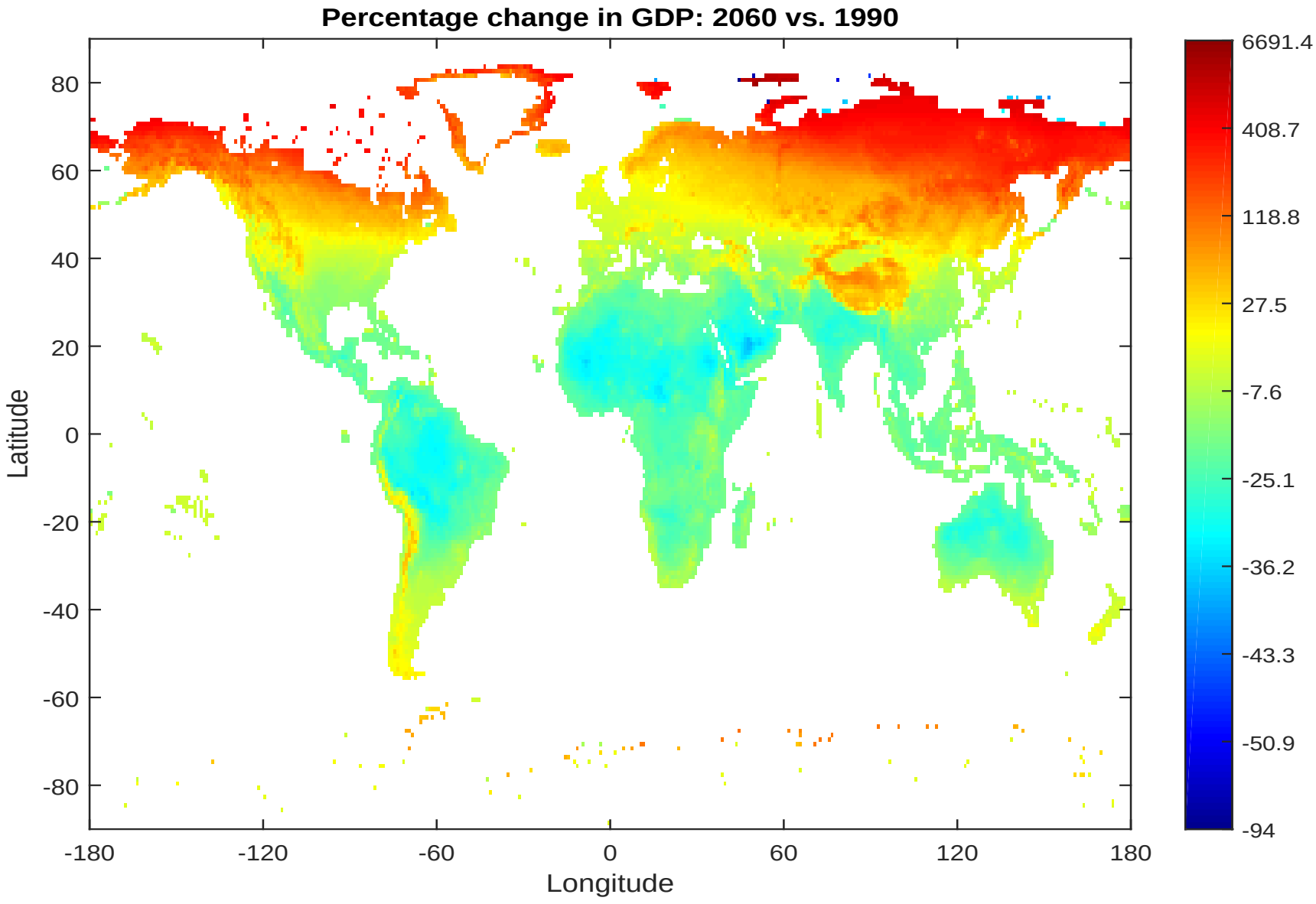
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2060 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
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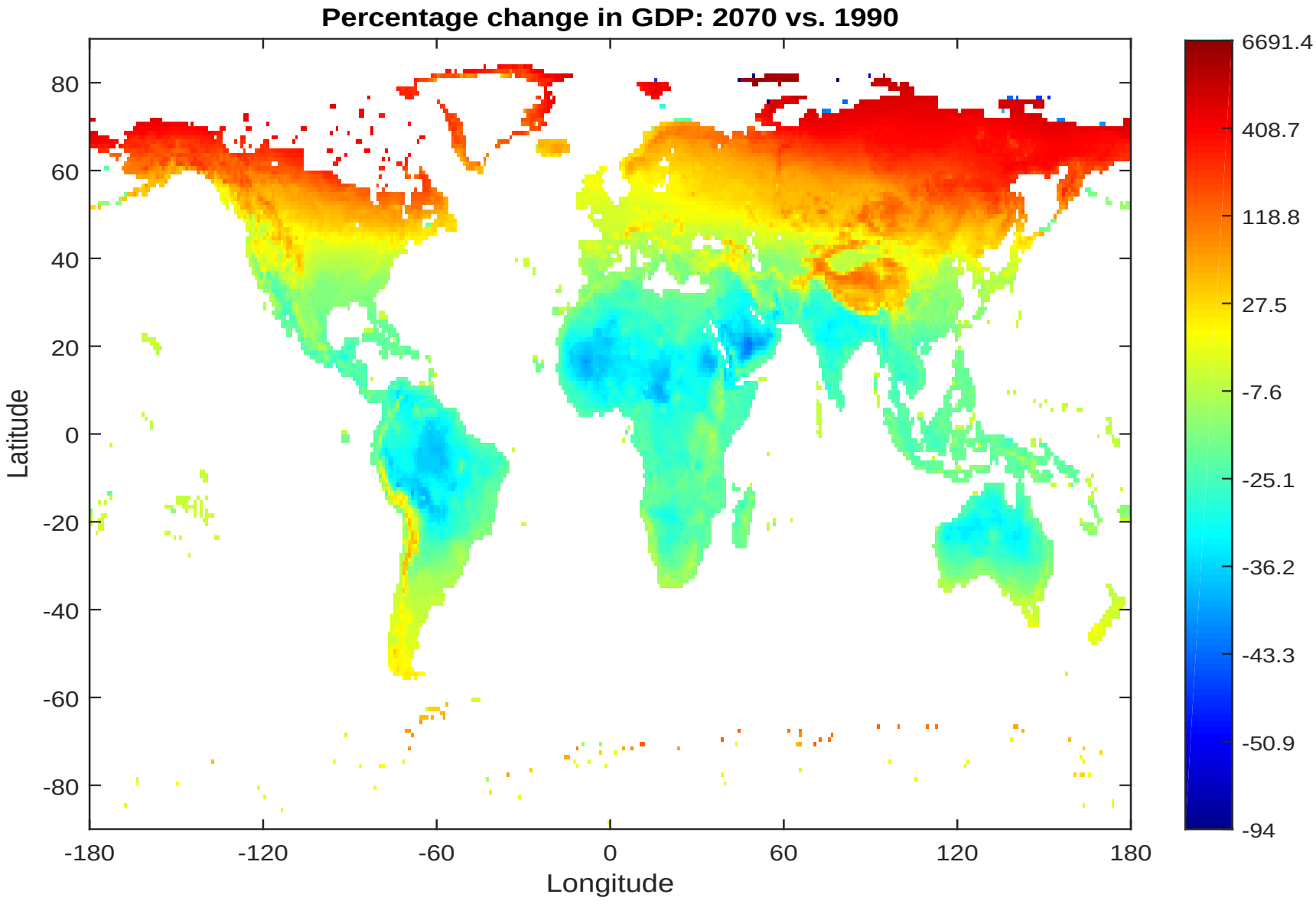
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2070 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
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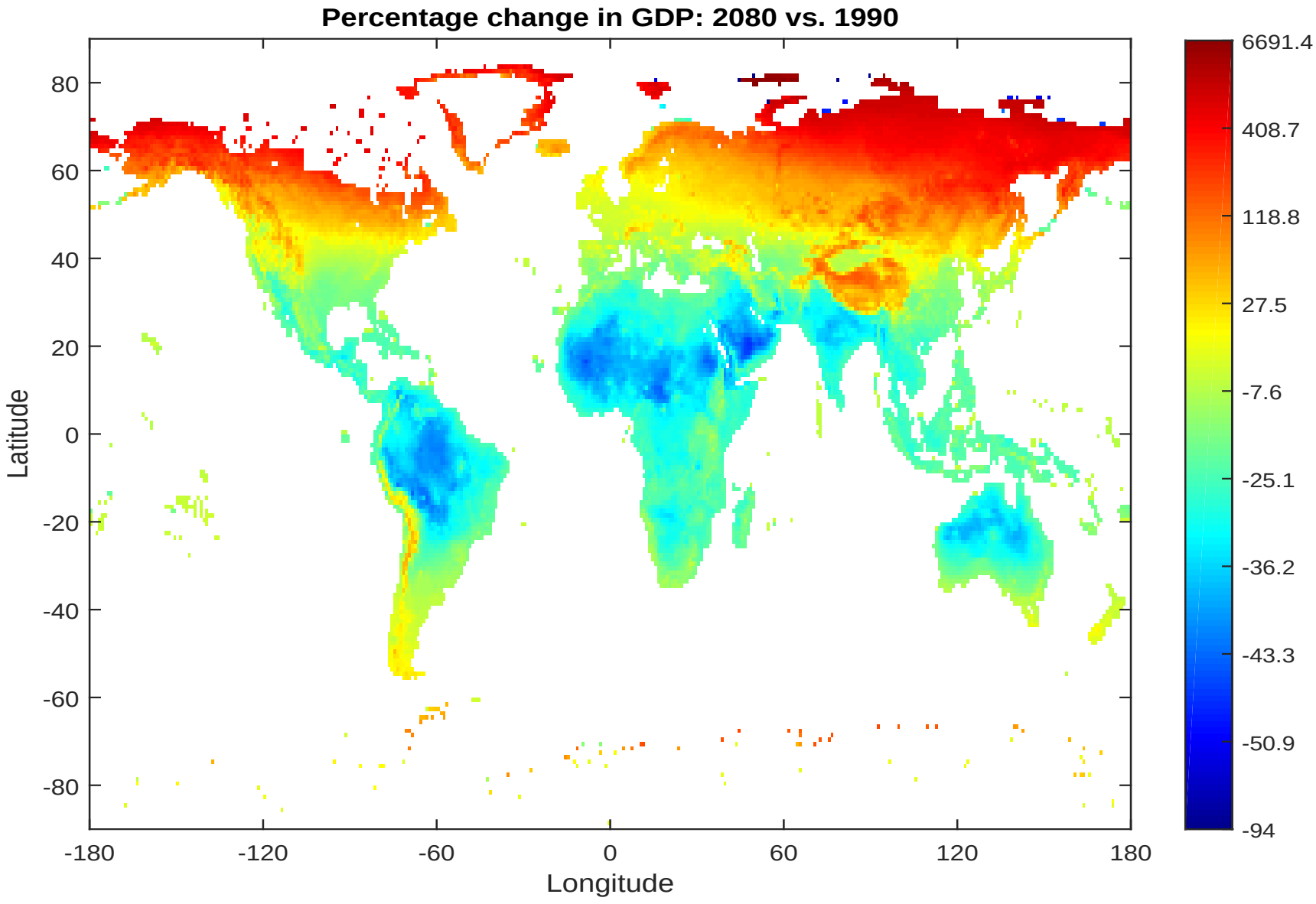
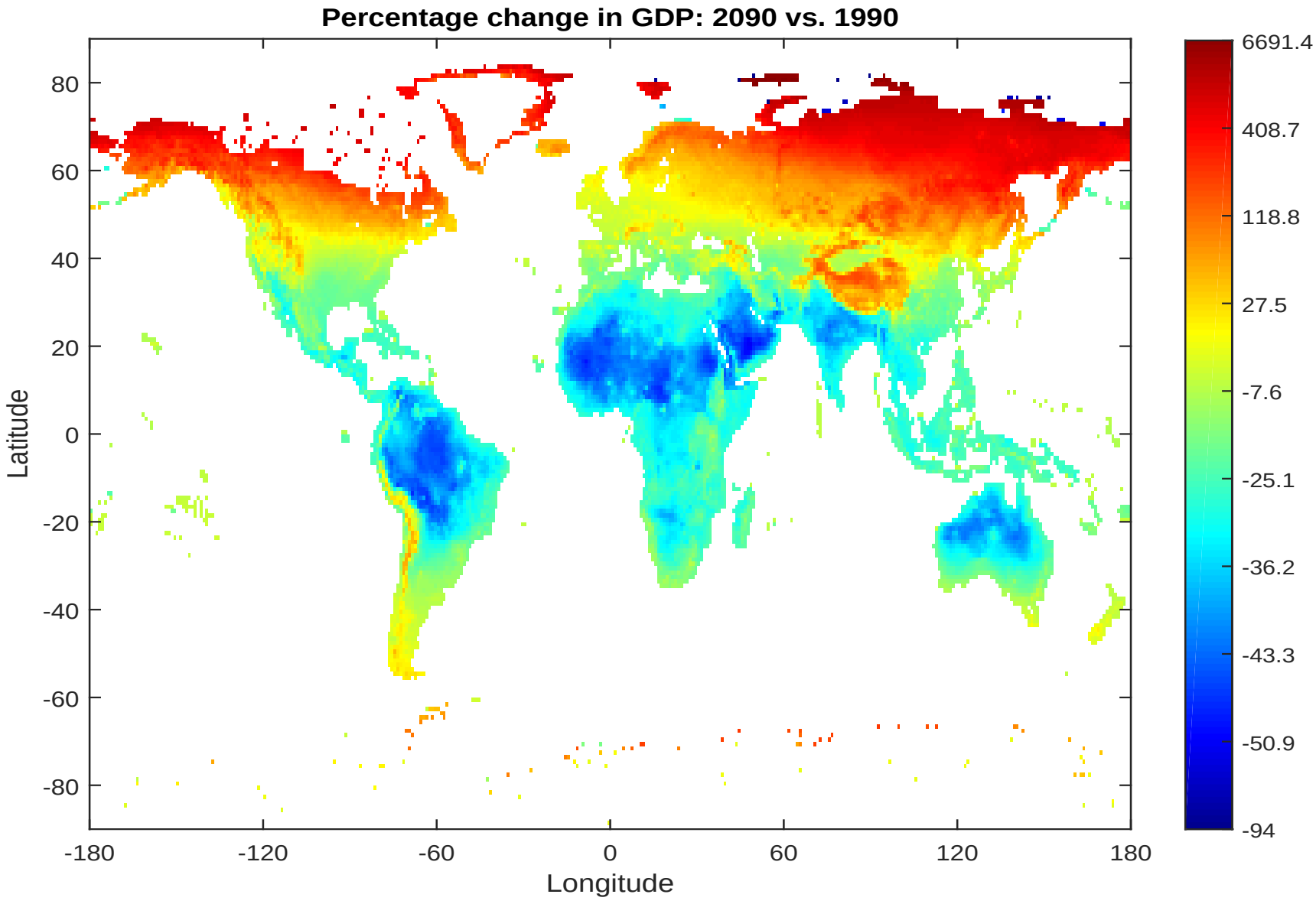
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2080 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2090 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
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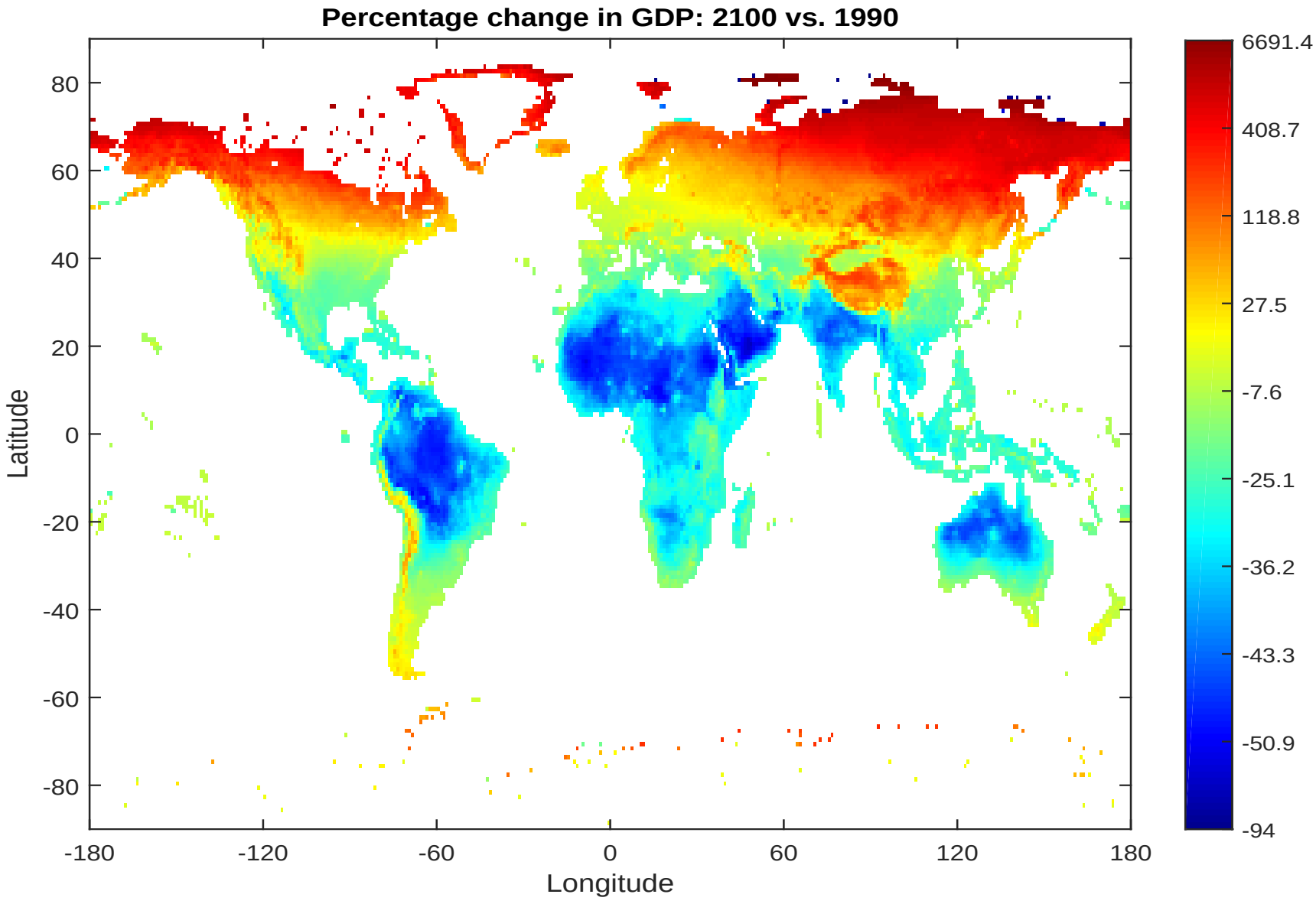
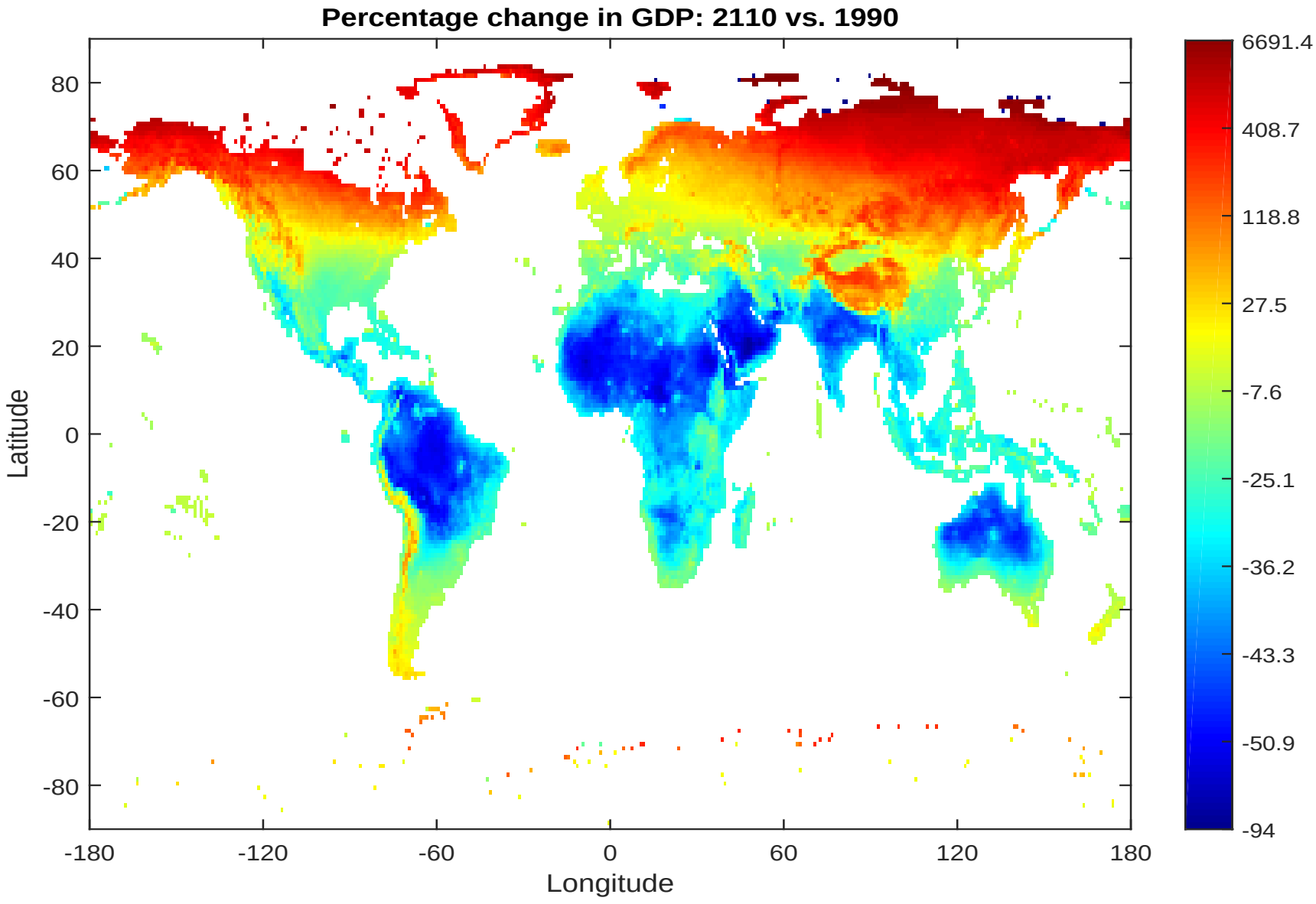
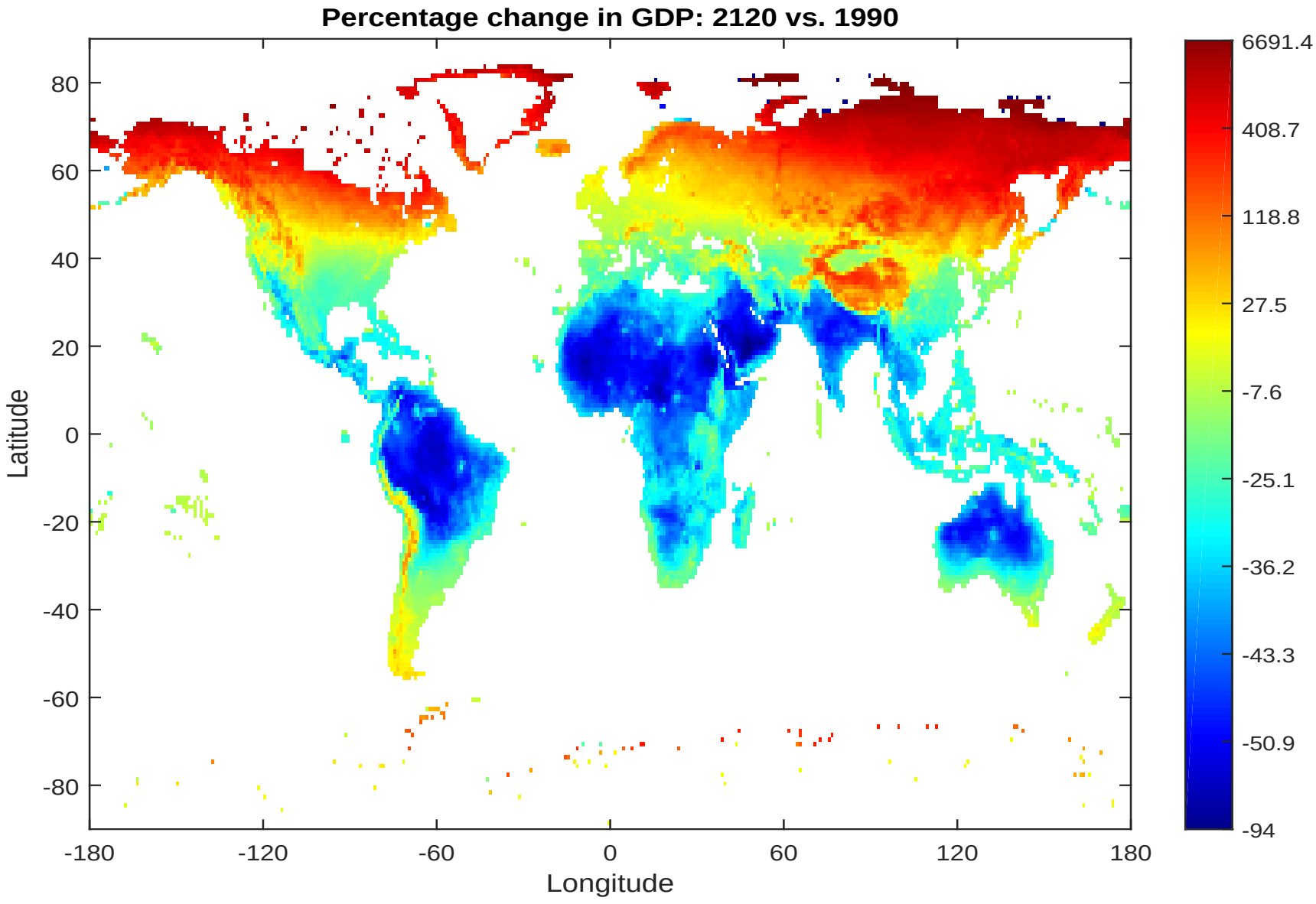
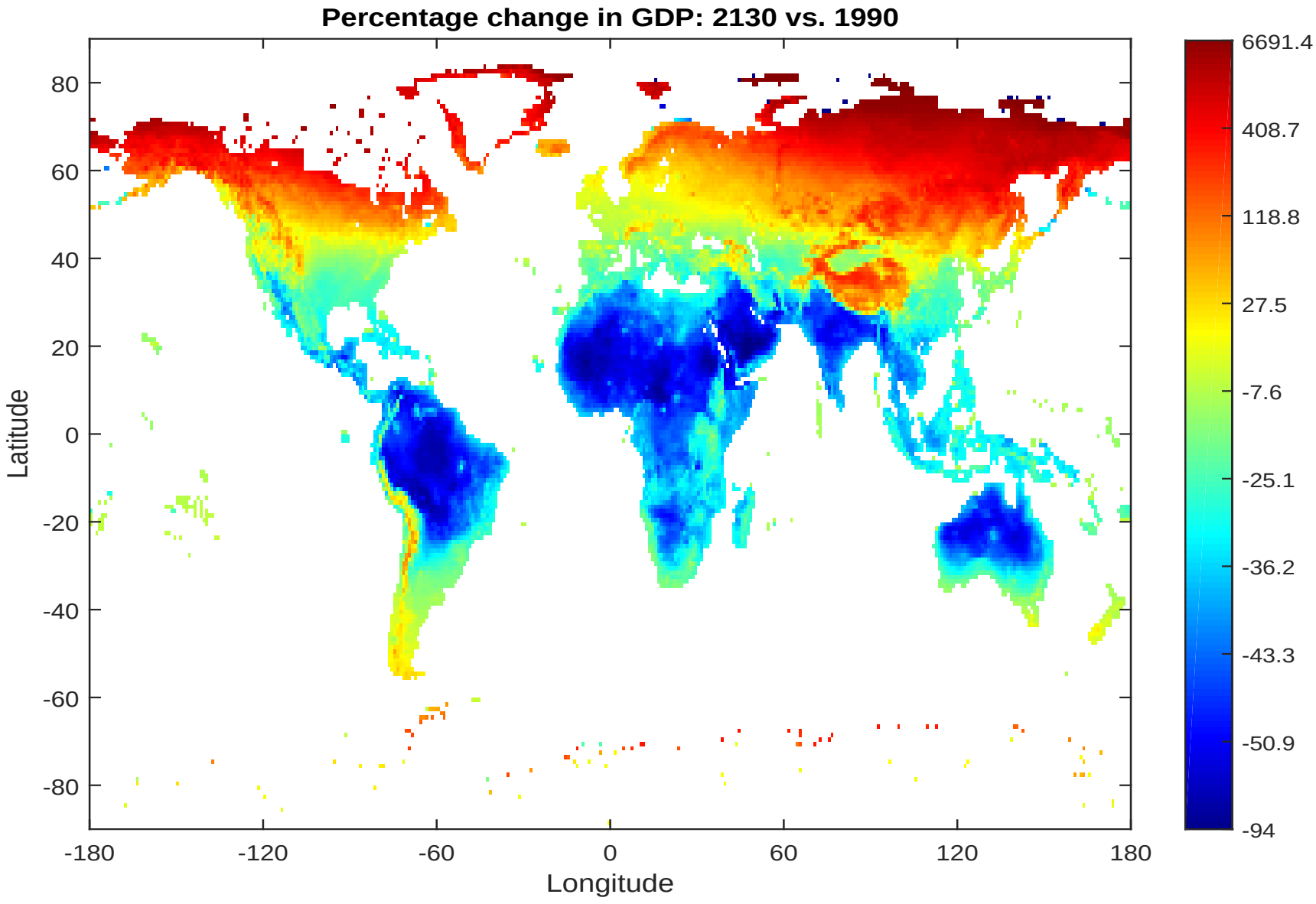
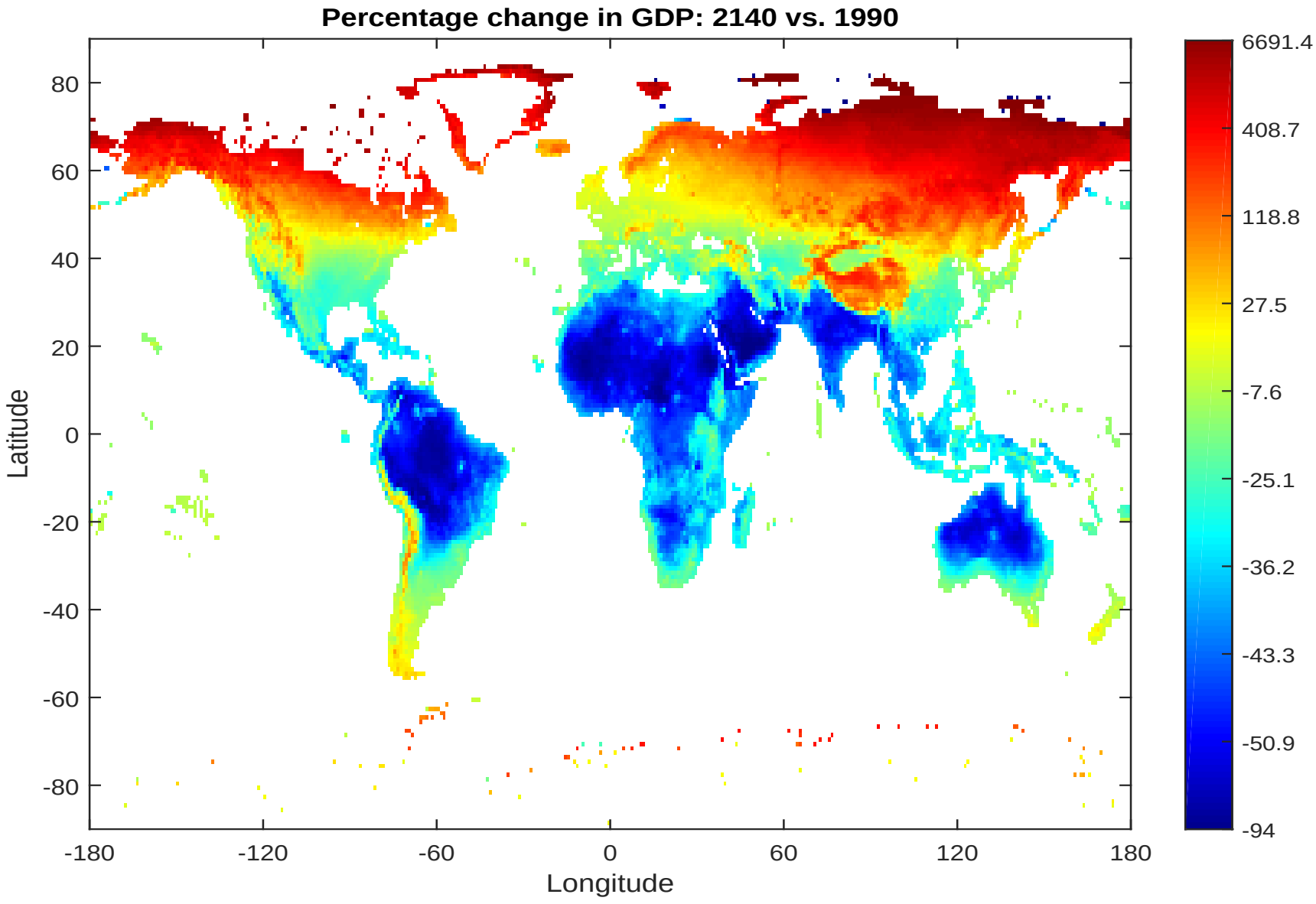
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

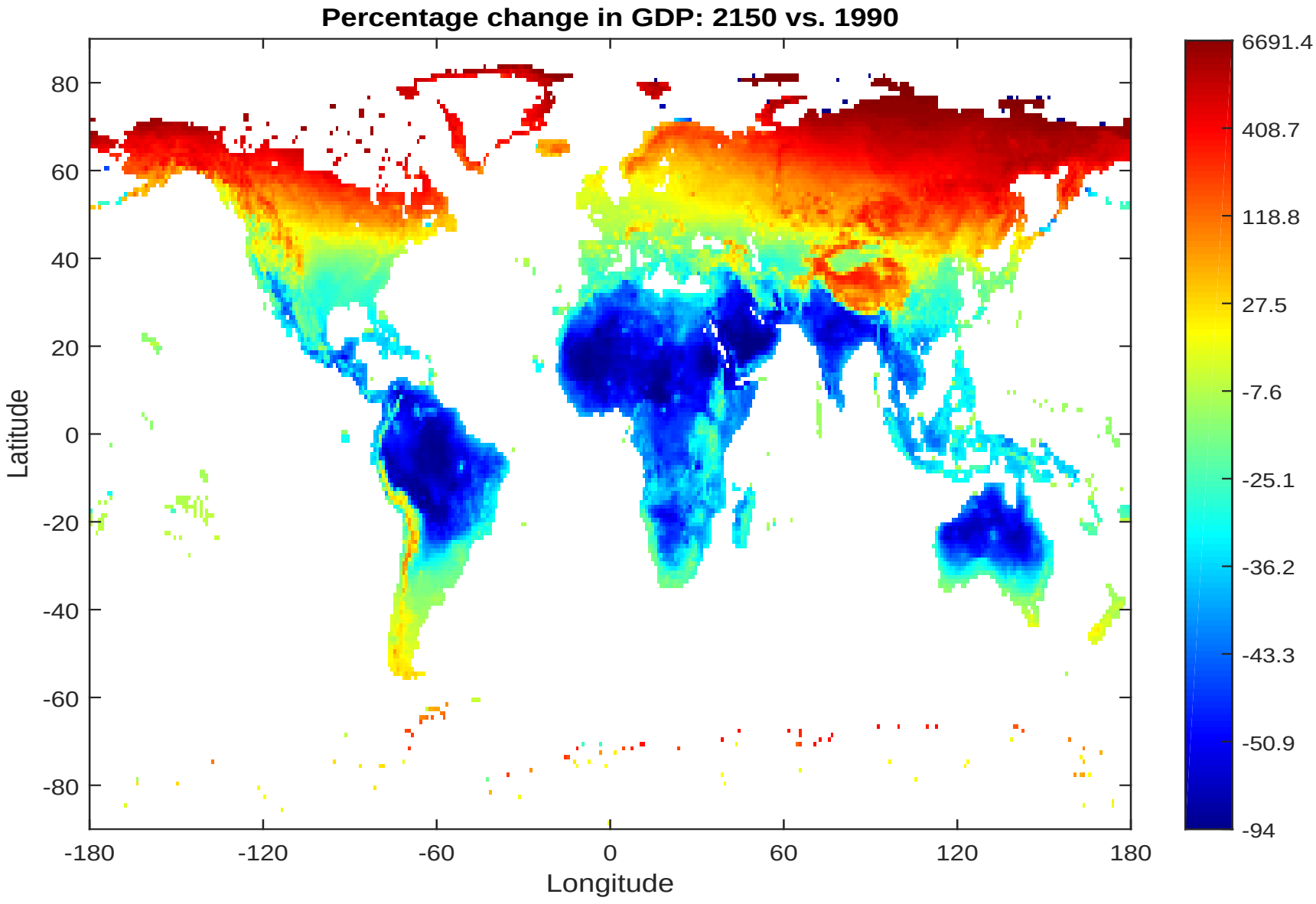

Percentage change in GDP: 2100 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

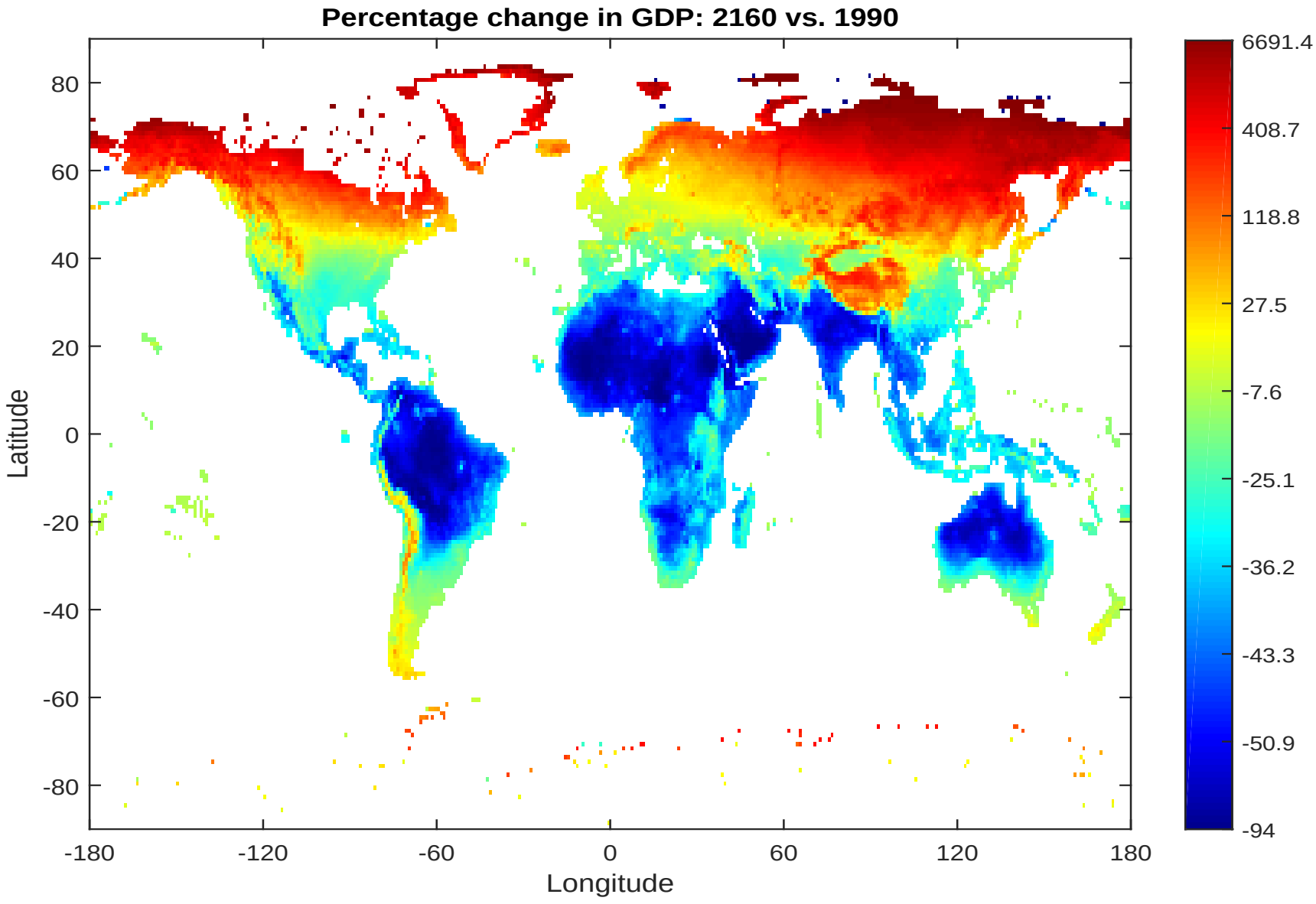

Percentage change in GDP: 2110 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

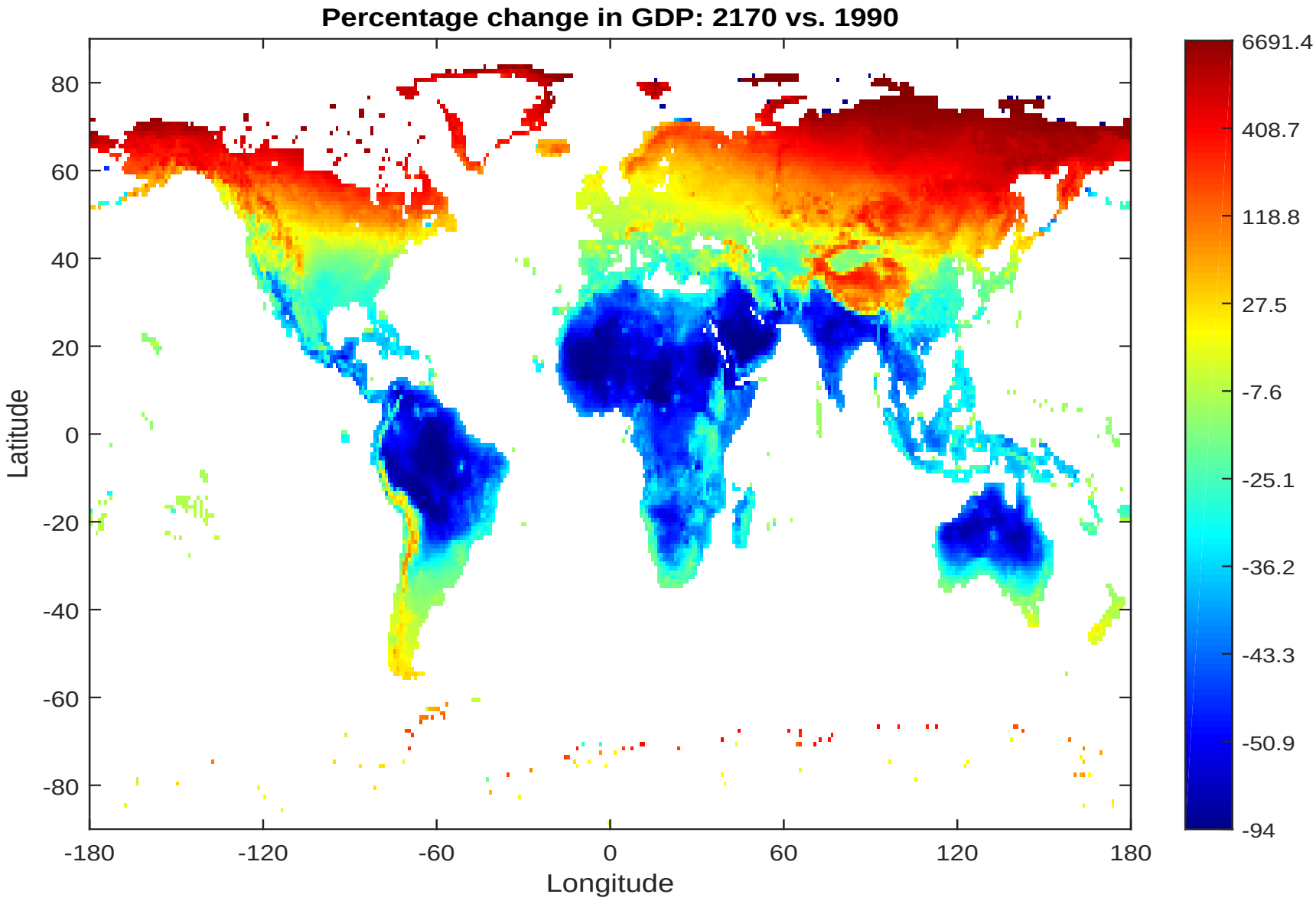

Percentage change in GDP: 2120 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

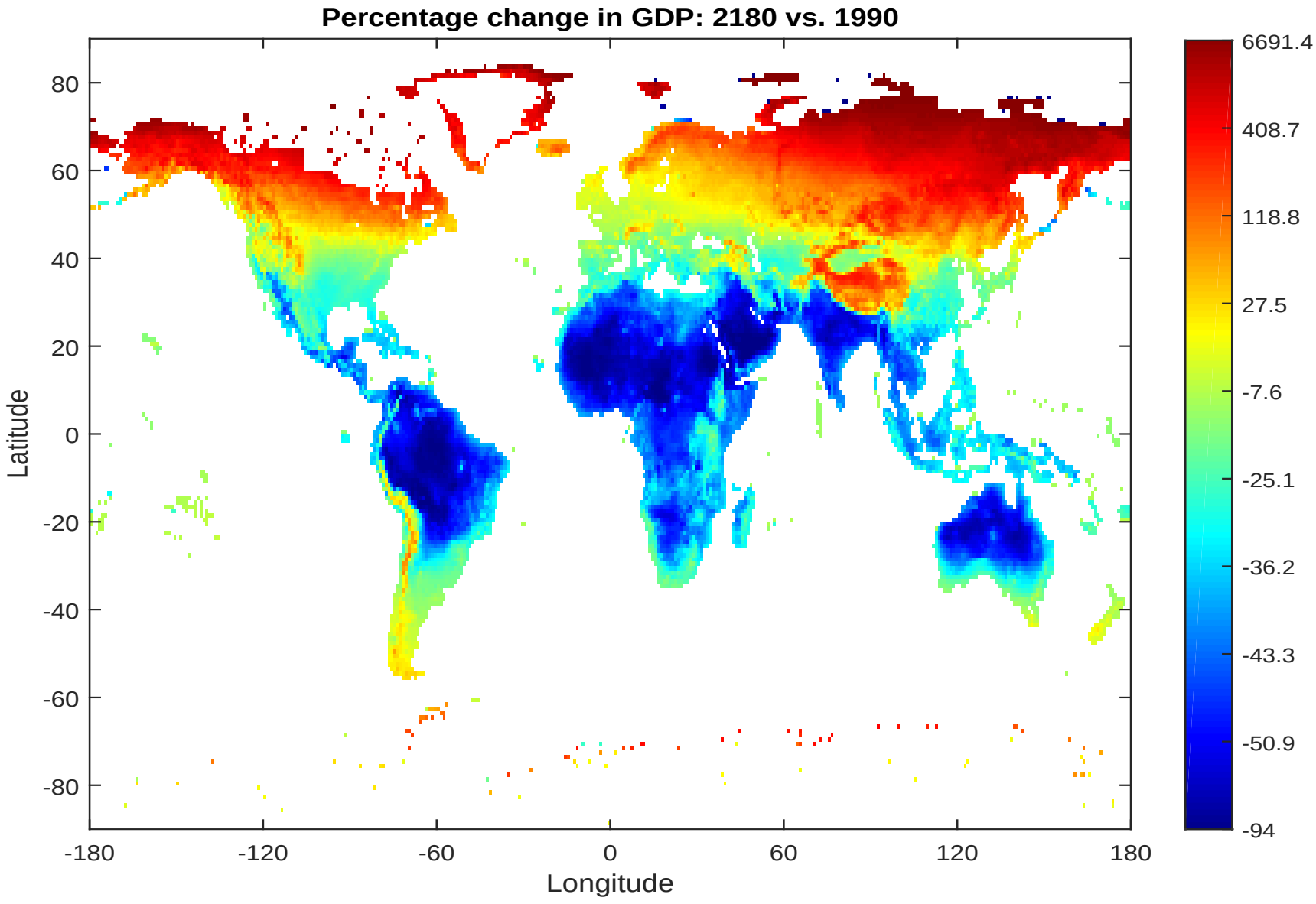

Percentage change in GDP: 2130 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

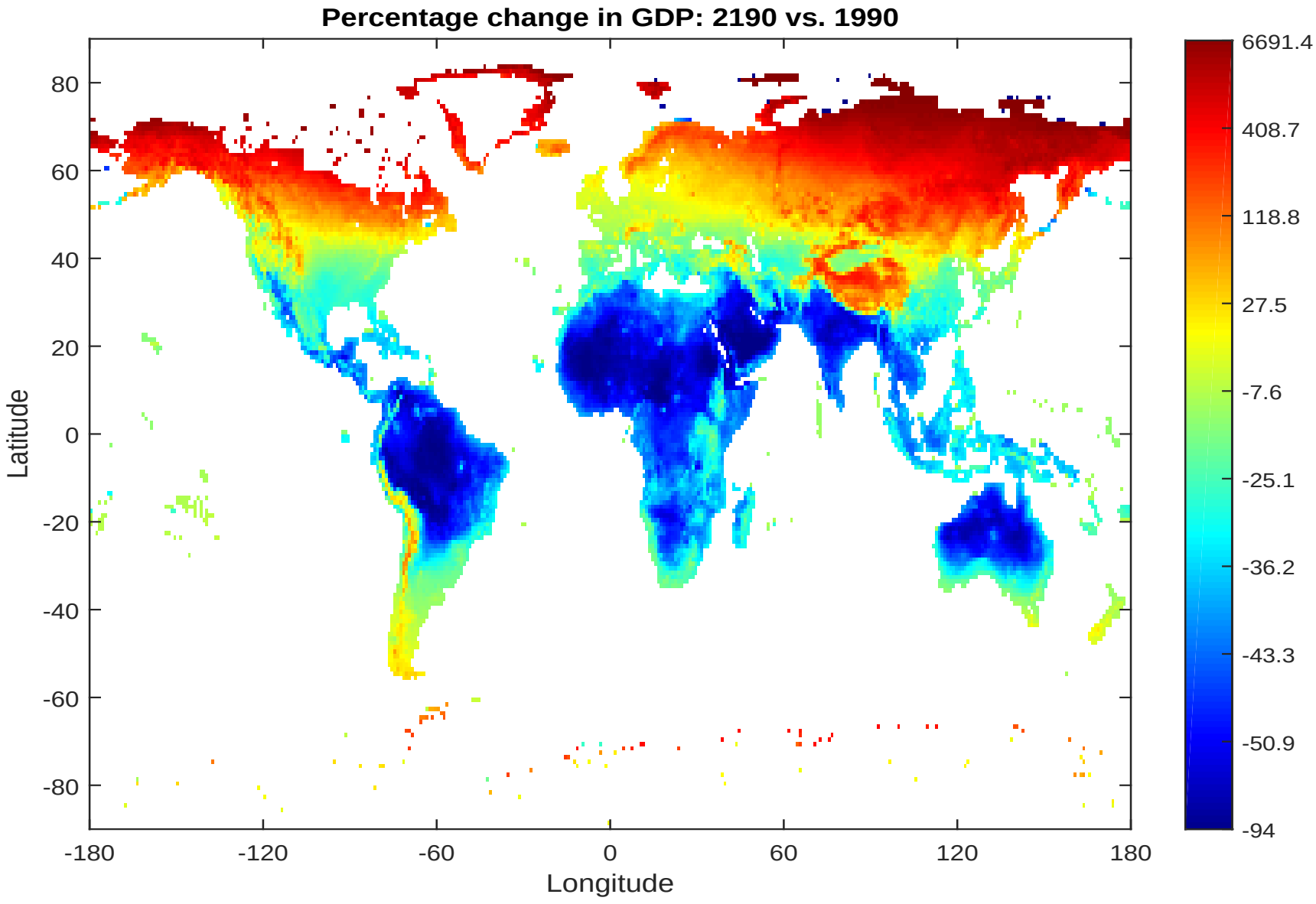

Percentage change in GDP: 2140 vs. 1990
Latitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
Longitude
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

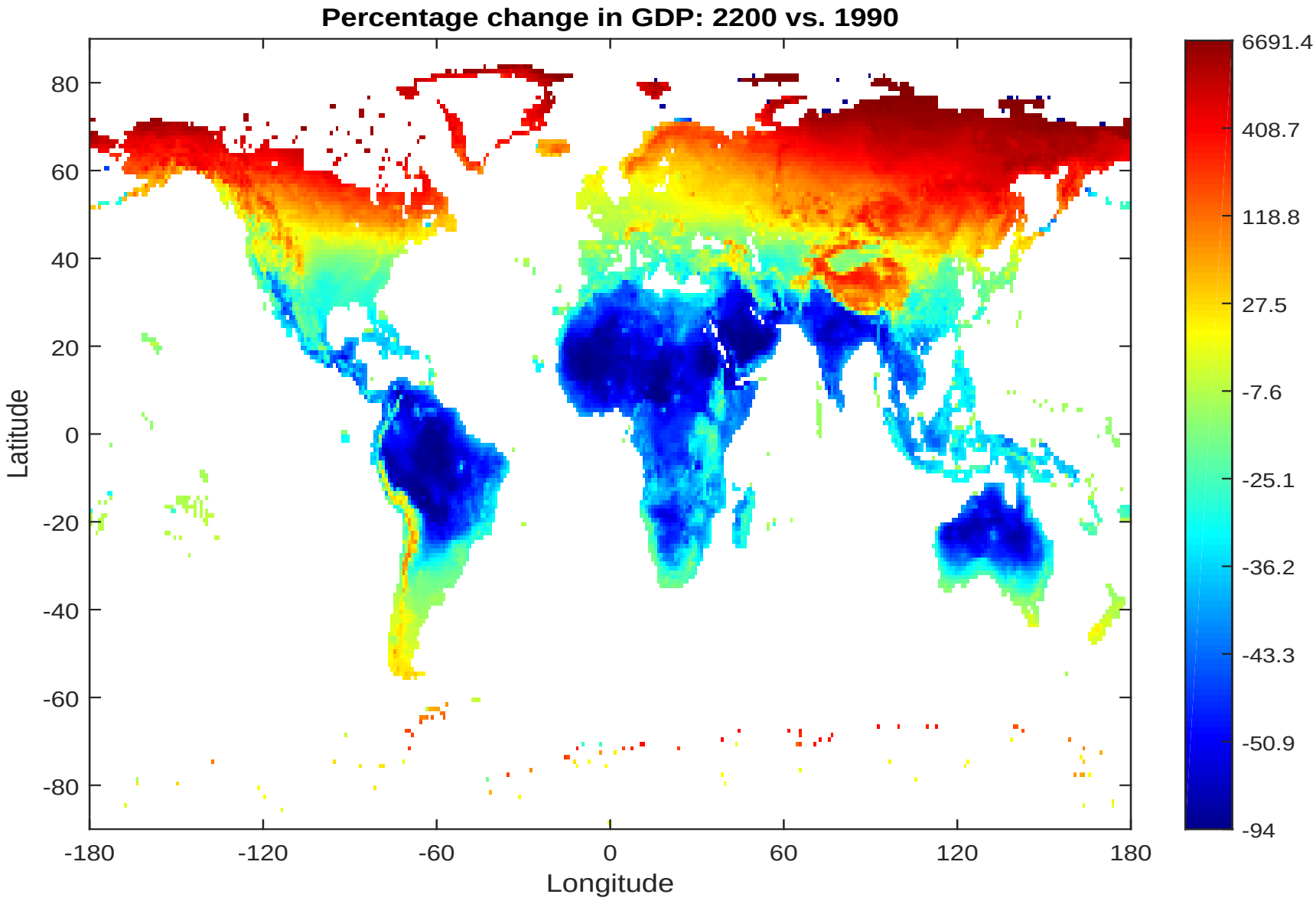

Percentage change in GDP: 2150 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2160 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2170 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2180 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2190 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94


Percentage change in GDP: 2200 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6691.4
408.7
118.8
27.5
-7.6
-25.1
-36.2
-43.3
-50.9
-94

Conclusions

Take-away:

- Results from our model: climate change is about relative effects much more than about average effects!
- In particular, huge disagreements about taxes (so huge transfer payments needed to compensate those losing from carbon tax).
- Methodological insight: we thought the market structure (because it admits more or less adaptation) would be important for the results, but it isn't.

Some caveats

- On one hand, damages "too local" and symmetric: no common aggregate damages. There are potentially such effects:
  - world technology development (level or growth) can be impacted;
  - biodiversity, ocean acidification, . . . ;
  - spillovers through trade, migration, tourism, . . .
- On other hand, maybe not enough regional heterogeneity yet (rural vs. urban, manufacturing vs. agriculture, . . .).

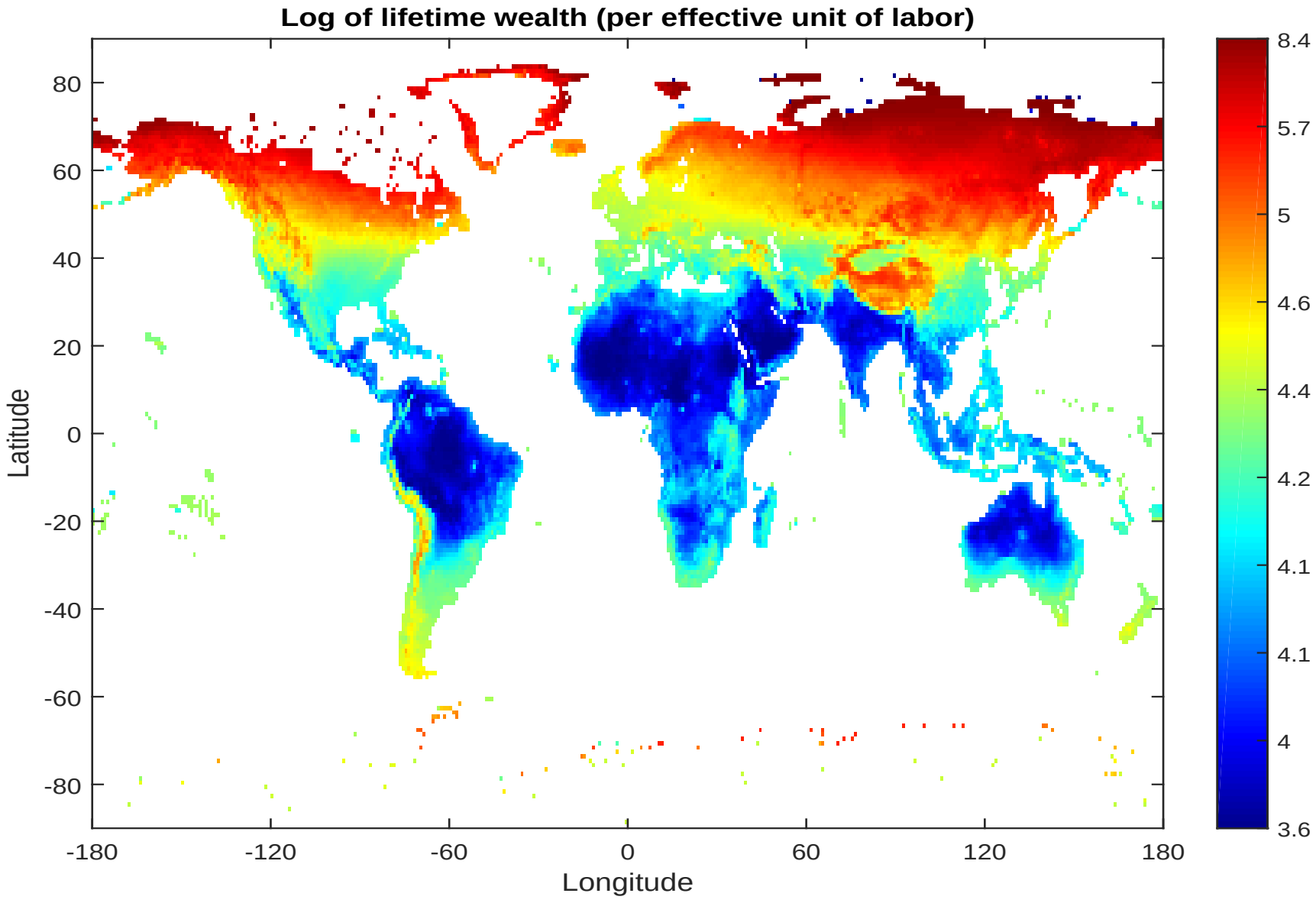
Near-future follow-up

Within present model/paper:

- How does climate change influence migration pressure at borders? Easy to compute. (PICTURE!)
- Heterogeneous taxes.

Applications:

- Temperature shocks; can be problematic at higher Ts because of extreme weather events (programs written, parallelizing done, some experiments run).
- Rising volatility as globe warms.
- Agricultural sector and food supplies (includes adding precipitation).
- ...


Log of lifetime wealth (per effective unit of labor)
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
8.4
5.7
5
4.6
4.4
4.2
4.1
4.1
4
3.6