Climate Change Around the World

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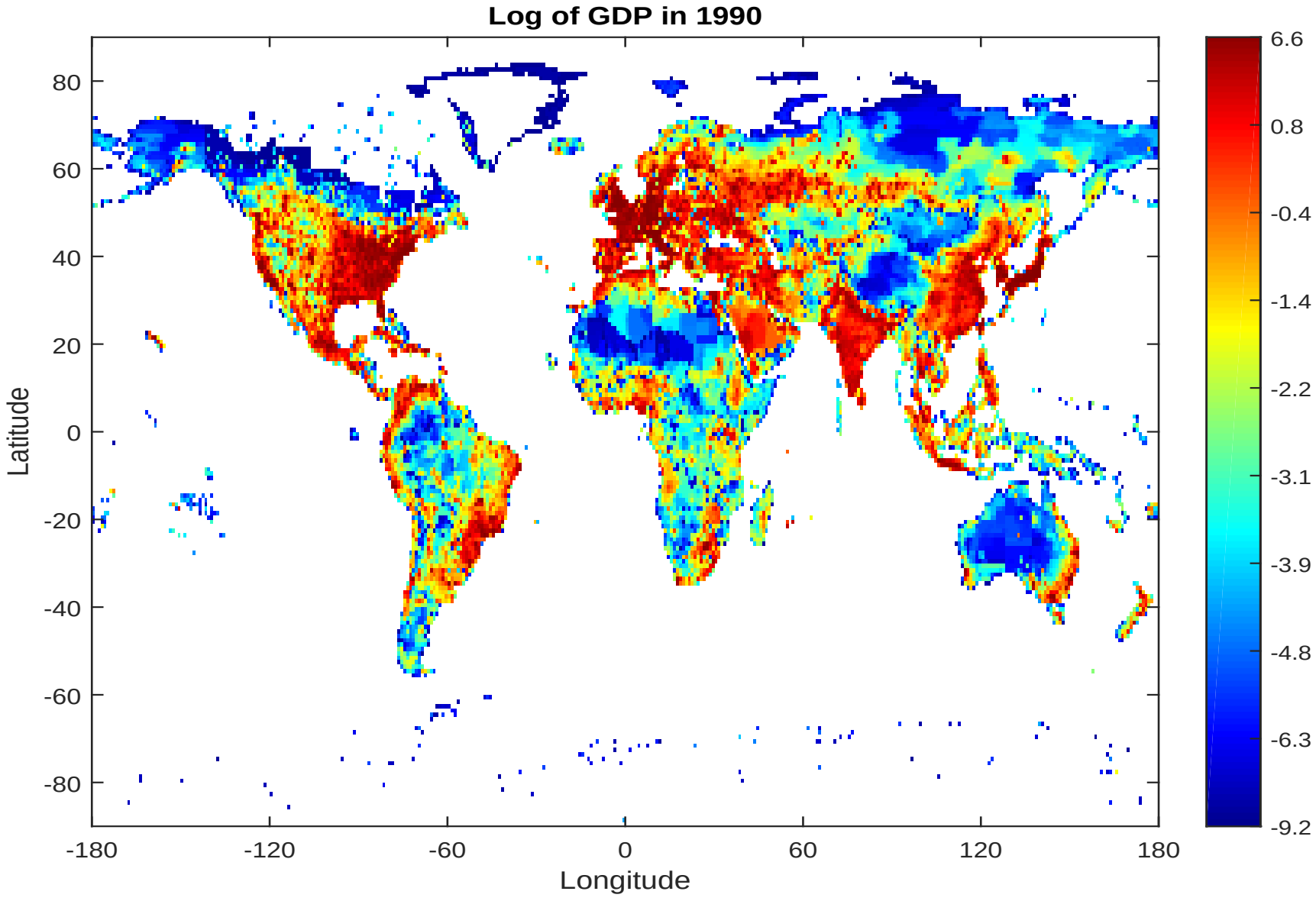
The project

- 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?

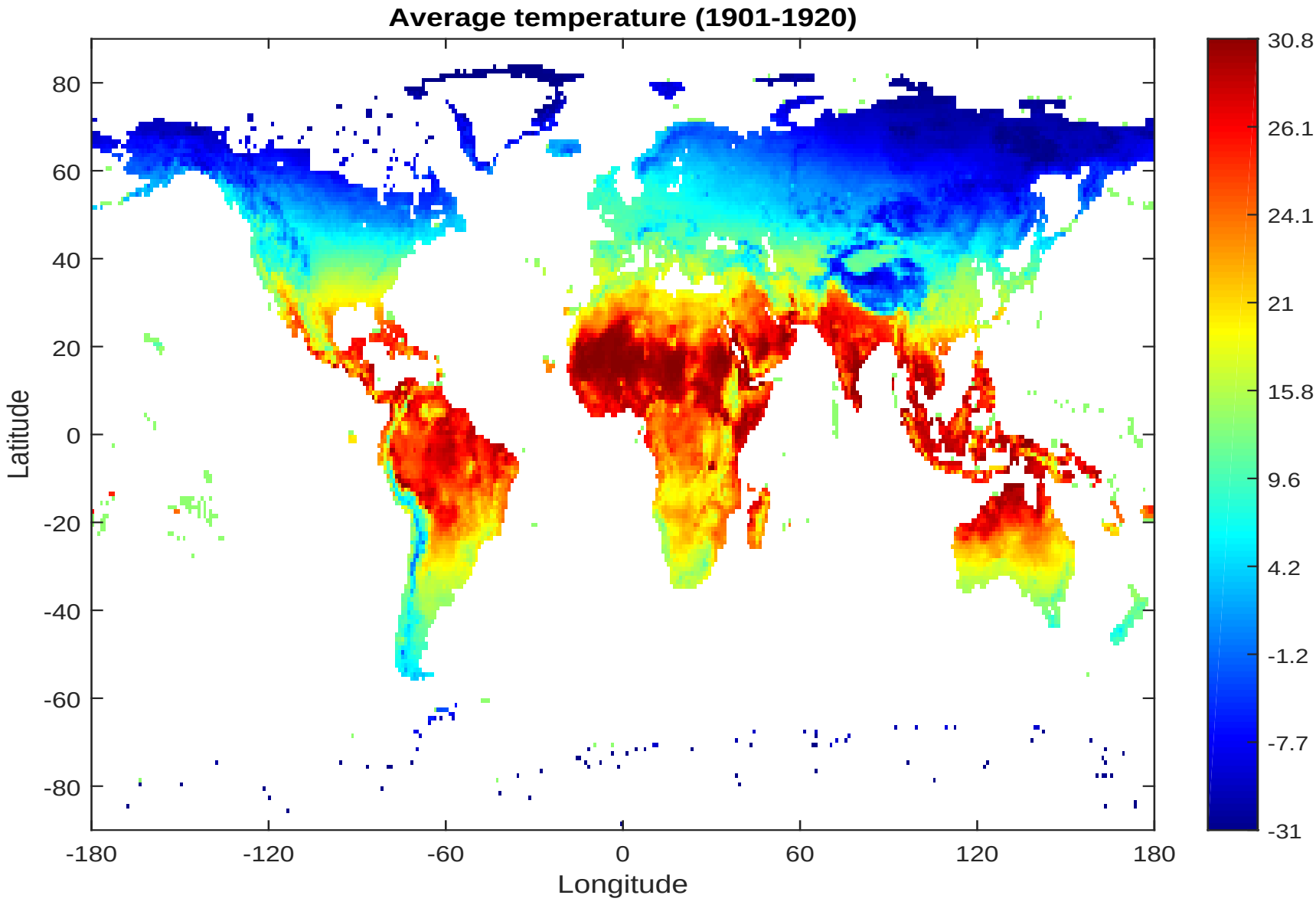
The data

- 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.

output 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

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
- key: insert simple-enough carbon cycle and climate models
- in particular, Golosov, Hassler, K, and Tsyvinski (GHKT; *Econometrica*, 2014) develops simple—but quantitatively specified—one-sector DSGE setting
- a multi-region pilot study in Hassler and K (HK; *Journal of European Economic Association*, 2012)

Build present structure on GHKT and HK.

We have incorporated "shocks" but these are not included today.

Overview for remainder of talk

1. our multi-region climate modeling
2. our multi-region damage specification
3. economic model
4. calibration
5. some simulations
6. conclusions

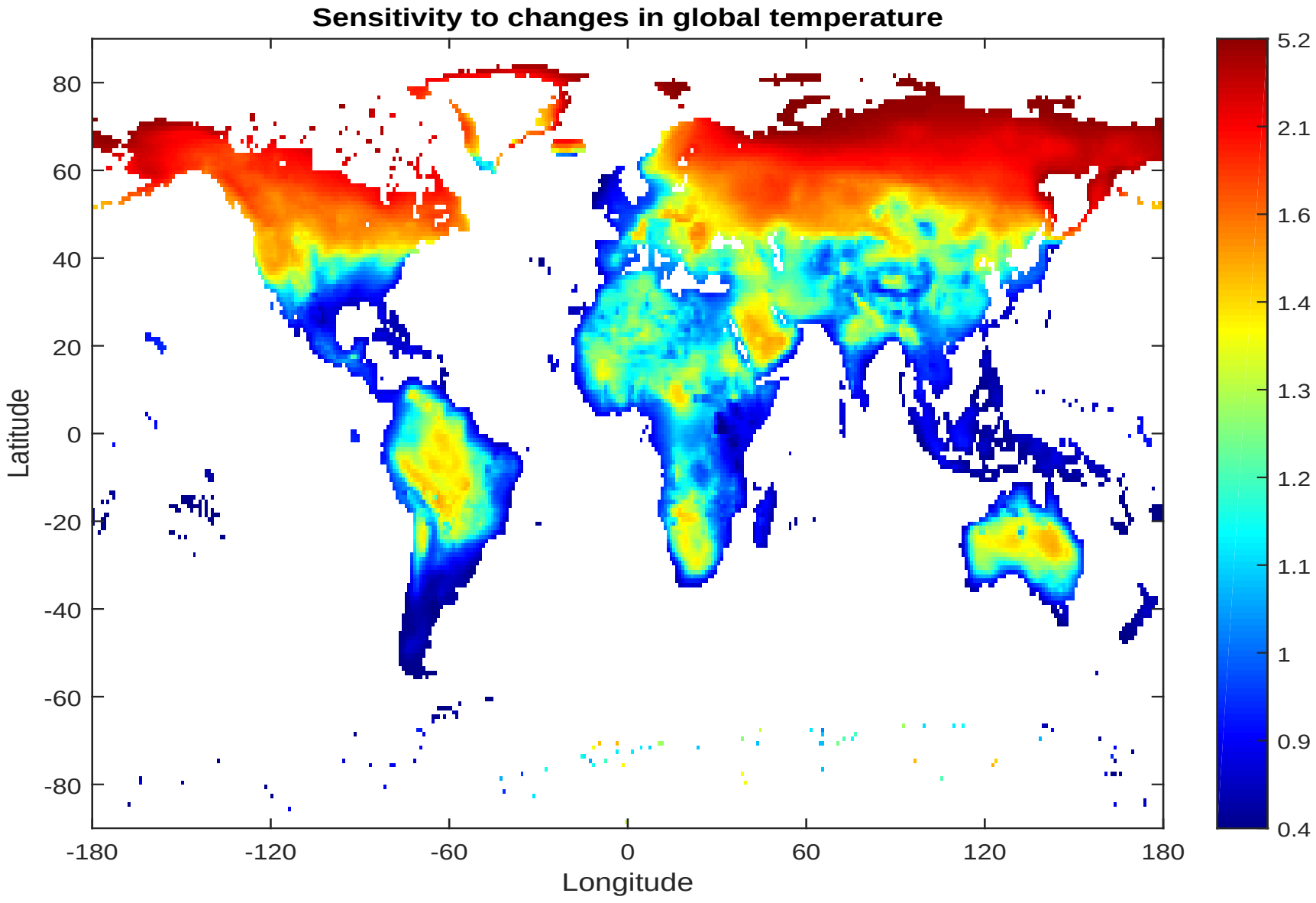
Our climate modeling

Standard modeling of aggregate climate (global temperature).

But how will region ℓ's climate respond to global warming?

- We 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 coefficient (linear structure; standard).
- Use runs of advanced 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

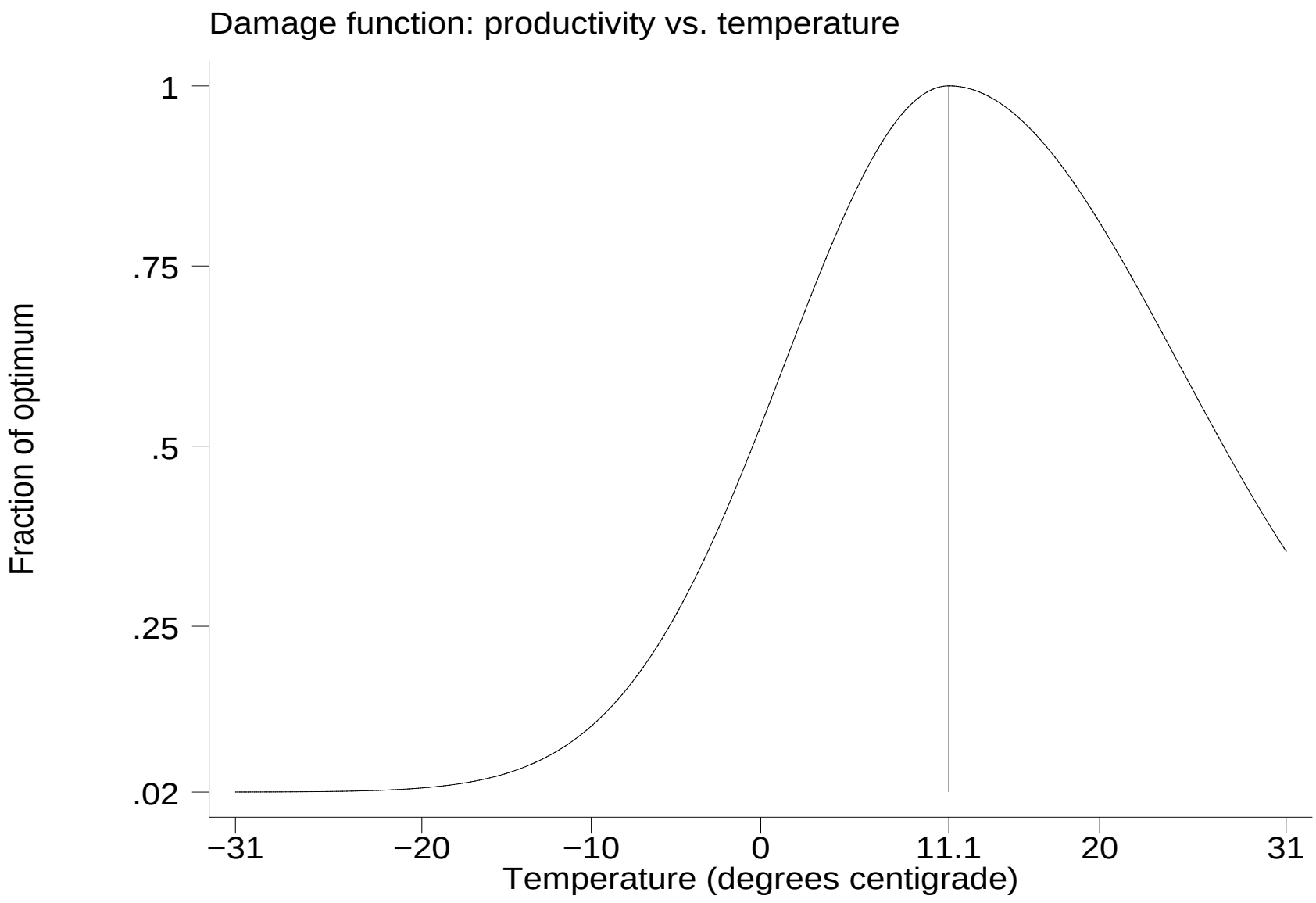

Sensitivity to changes in global temperature
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
5.2
2.1
1.6
1.4
1.3
1.2
1.1
1
0.9
0.4

Our damage specification

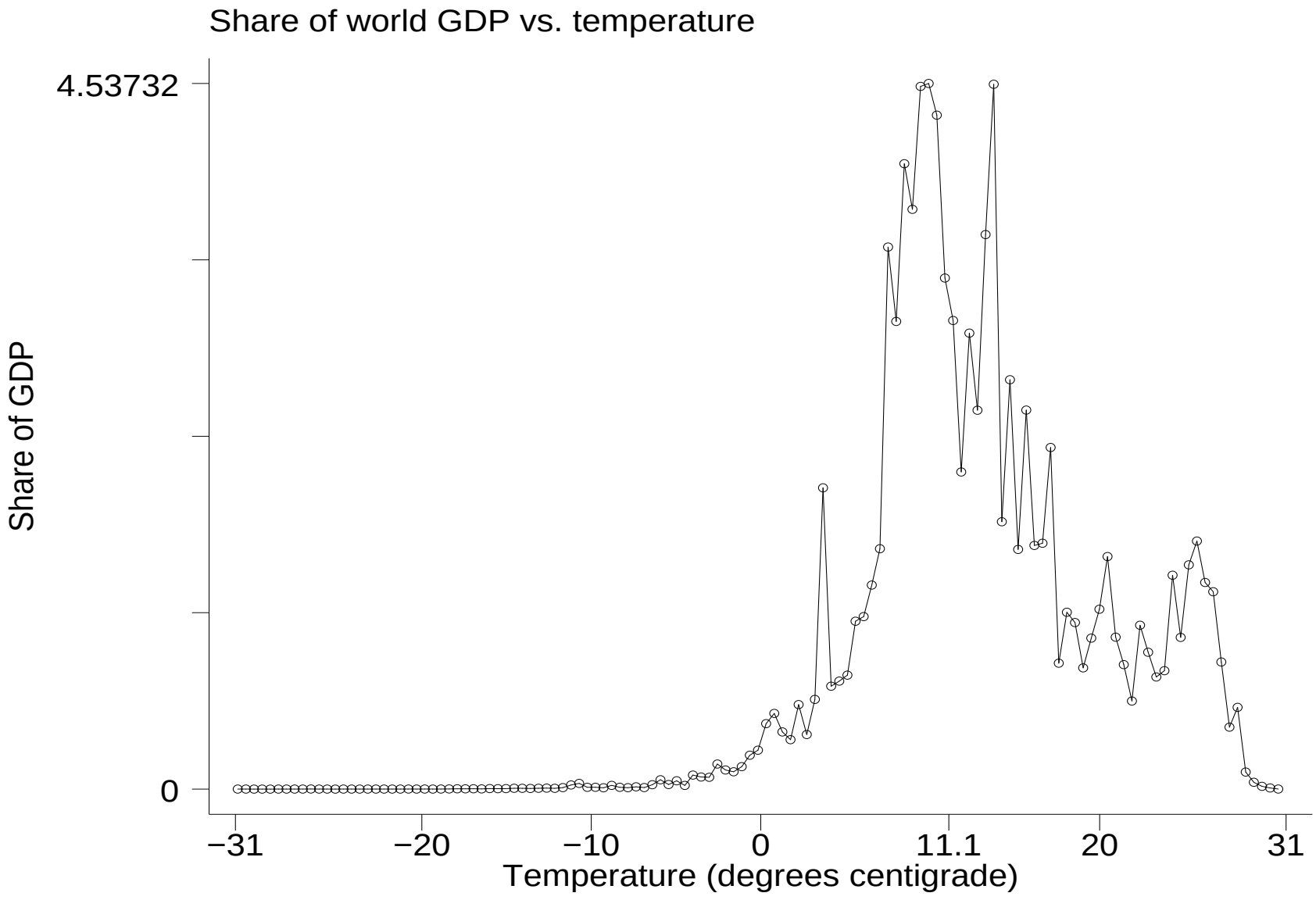
What are the damages in region ℓ as a result of global warming?

- We use 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, 0 damages at 0 degrees above preindustrial
    - three points used: at 1 degree centigrade, 0.3% output drag; at 2.5, 1.8%; and at 5, 6.8%.
- Cf. Burke et al. (2015)

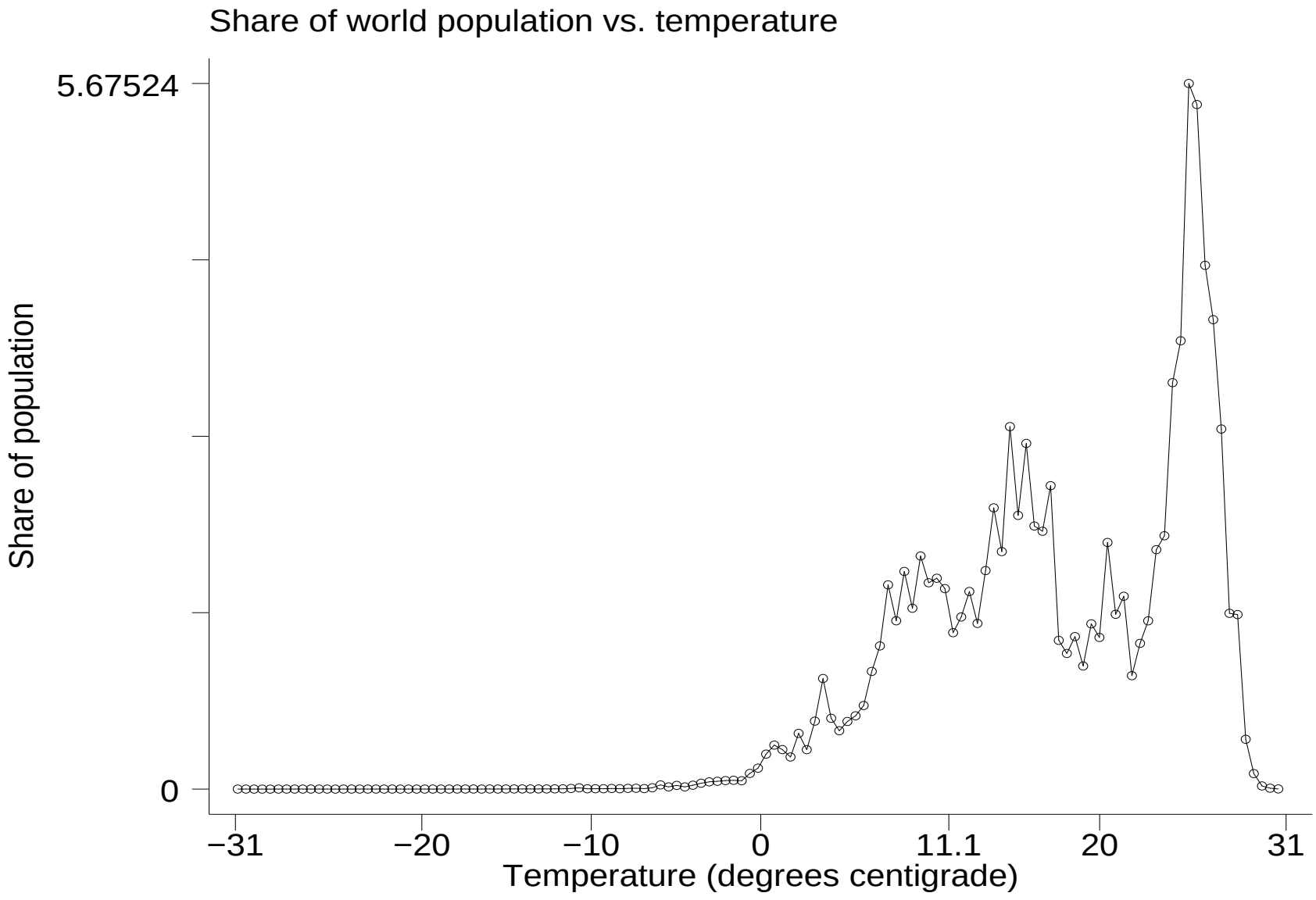
picture of 1 minus estimated U-shaped damage function, as function of local temperature


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)

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 Krusell and Smith (1998), 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 (w. arbitrary taxes).
- 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).

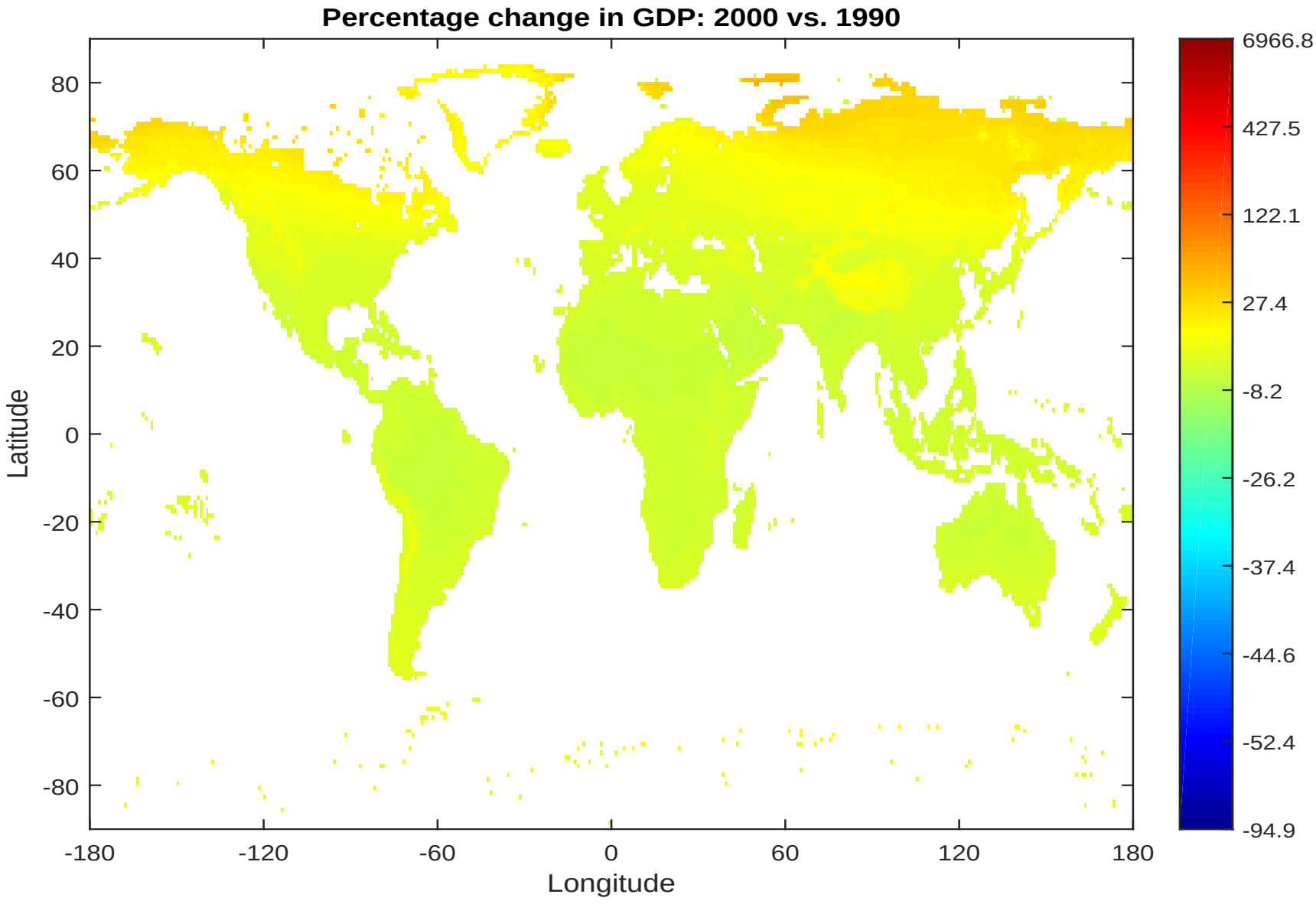
Experiment and main findings

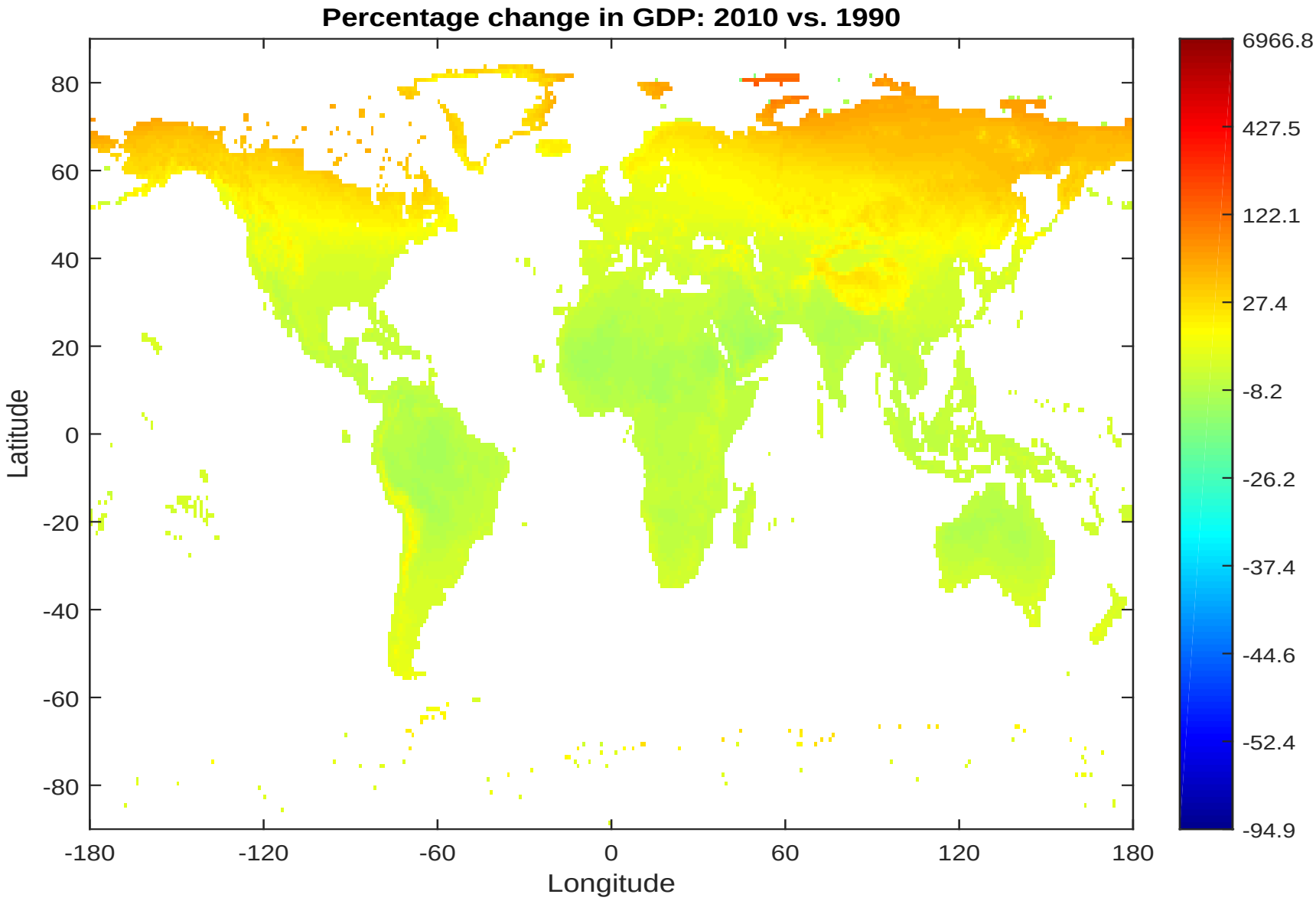
A laissez-faire experiment and a small tax on carbon.

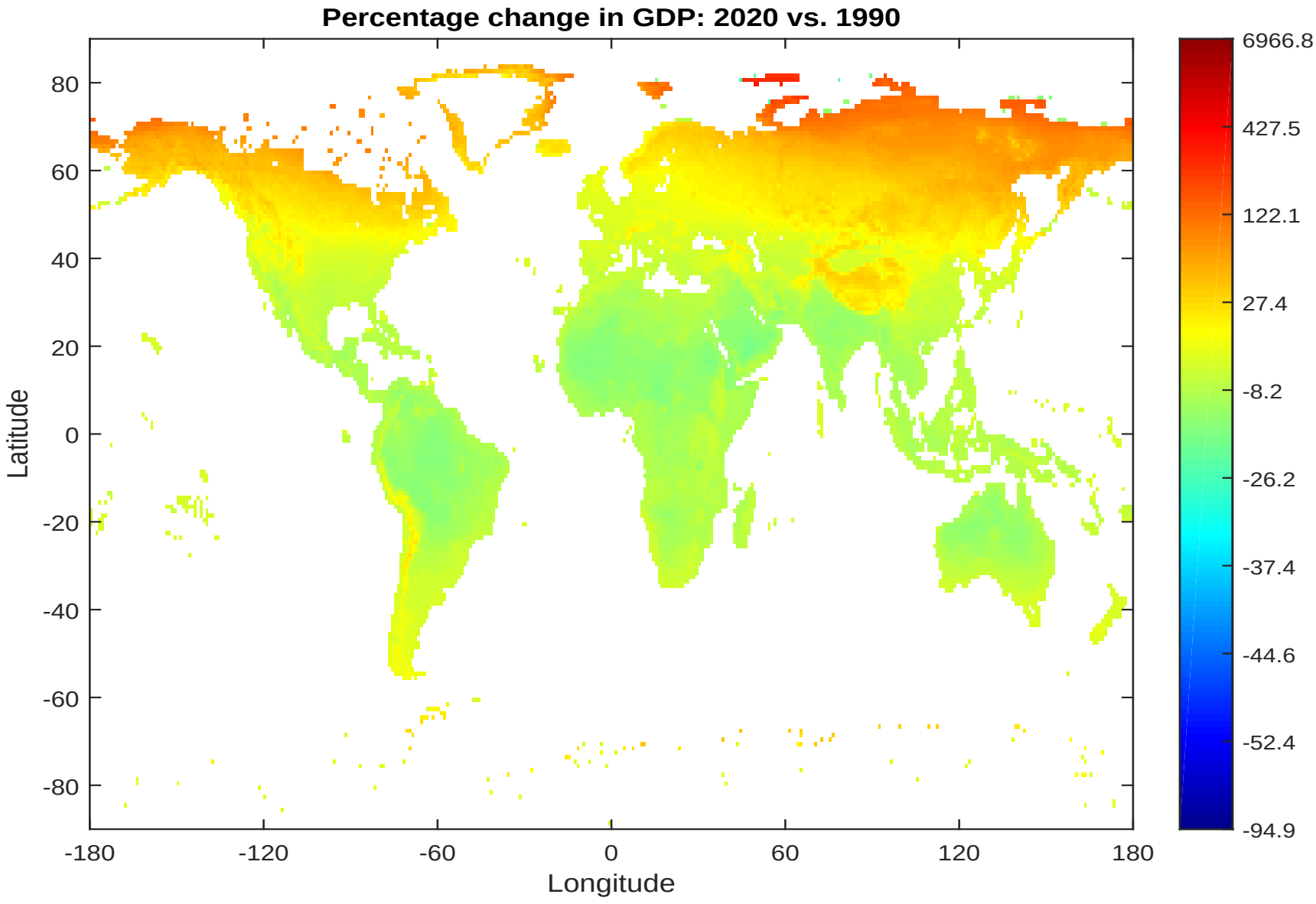
Findings:

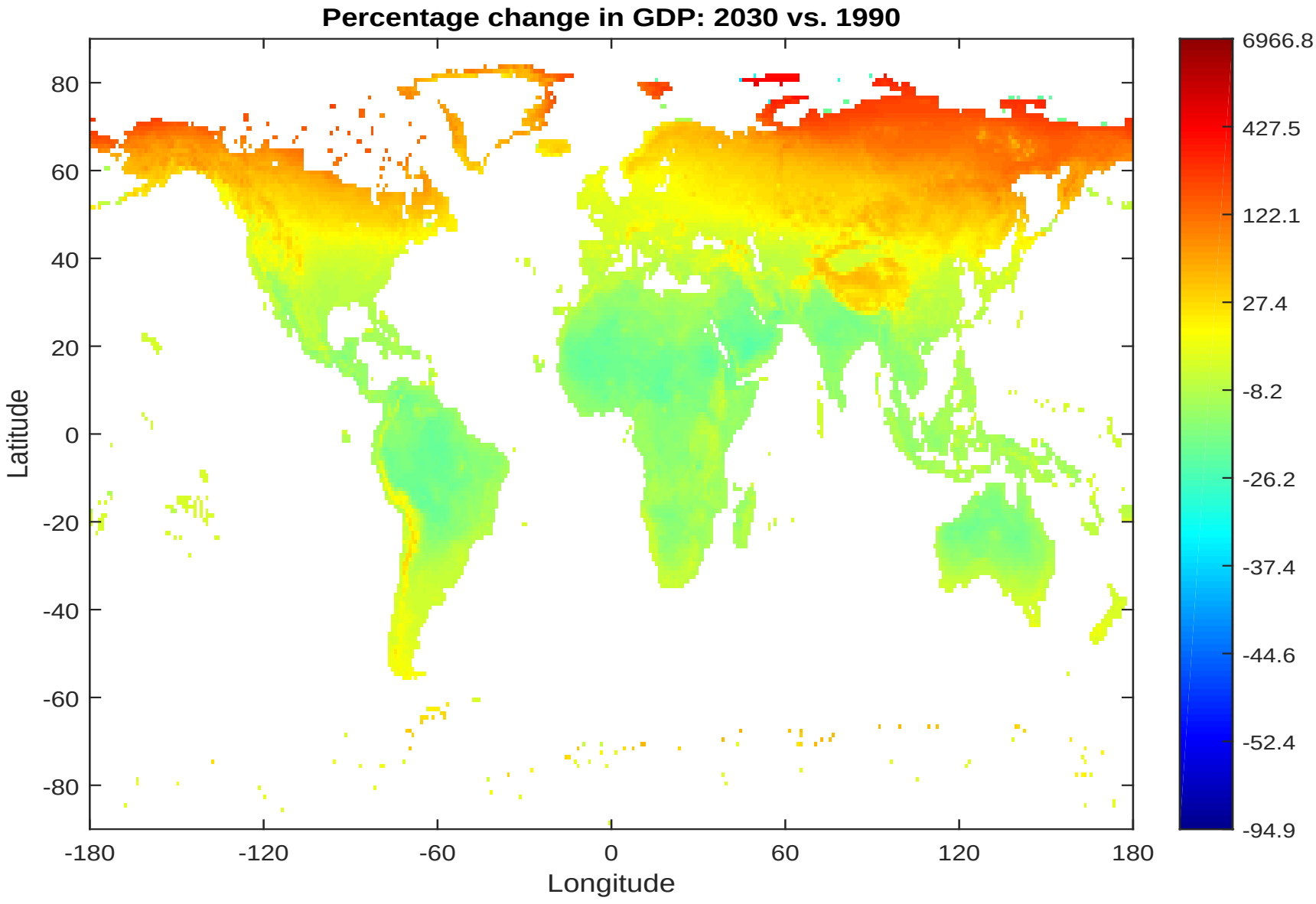
- Climate change affects regions *very* differently. Stakes big at regional level.
- Though a tax on carbon would affect welfare positively in some average sense, huge disparity of views: 55% of regions for tax, 45% against.
- Strong migration pressures from climate change.

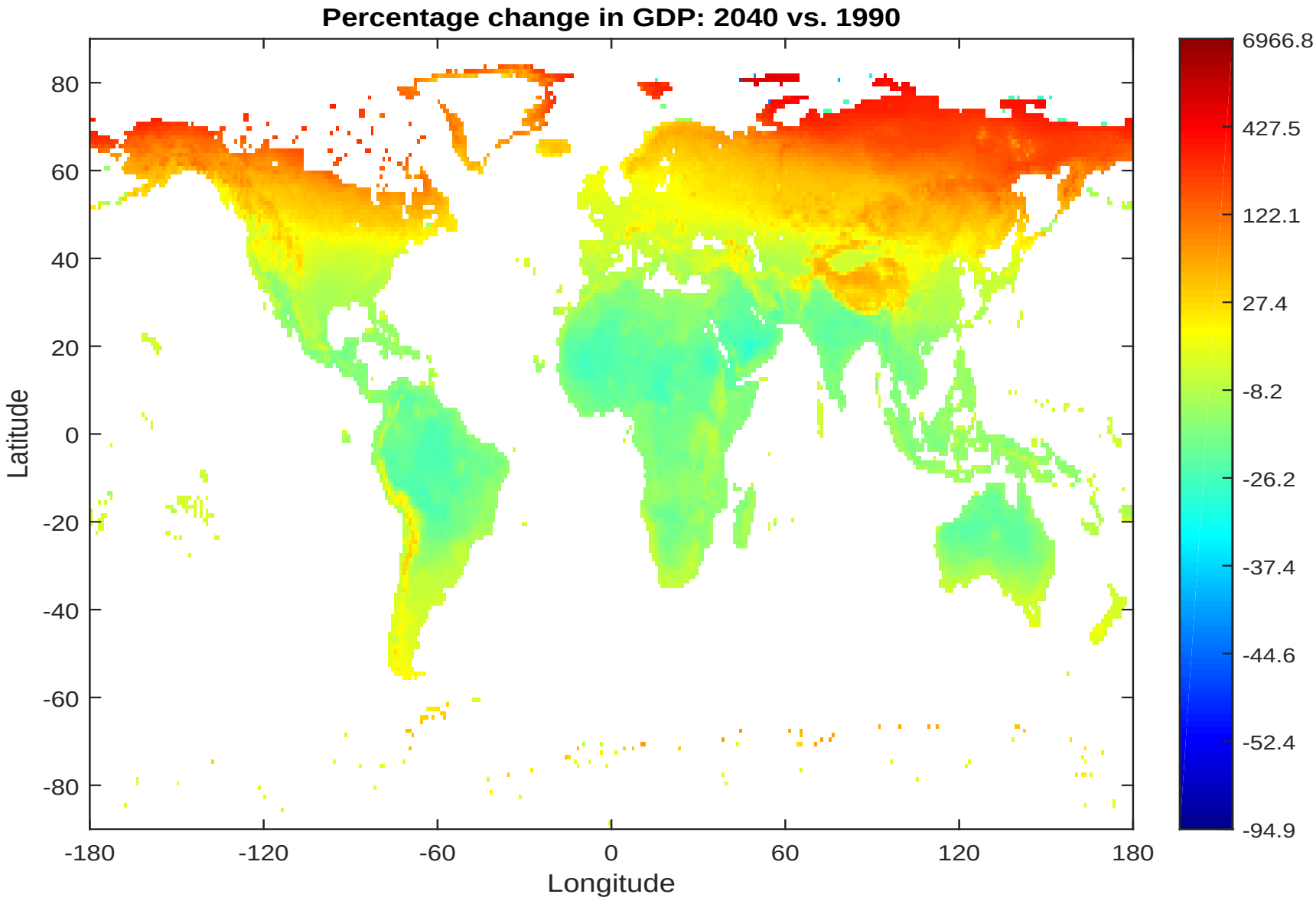
movie: percentage change in gdp, laissez-faire

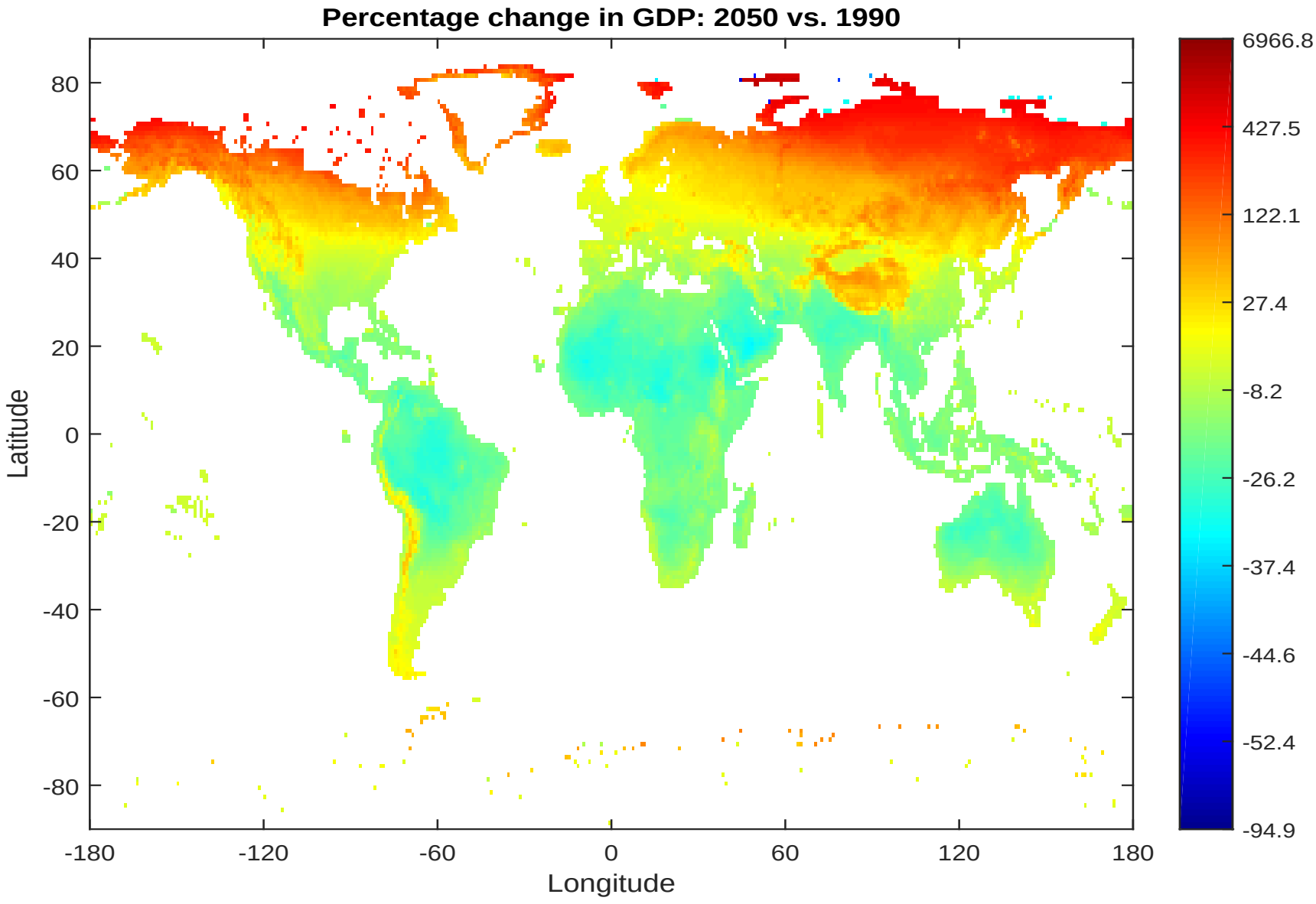

Percentage change in GDP: 2000 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

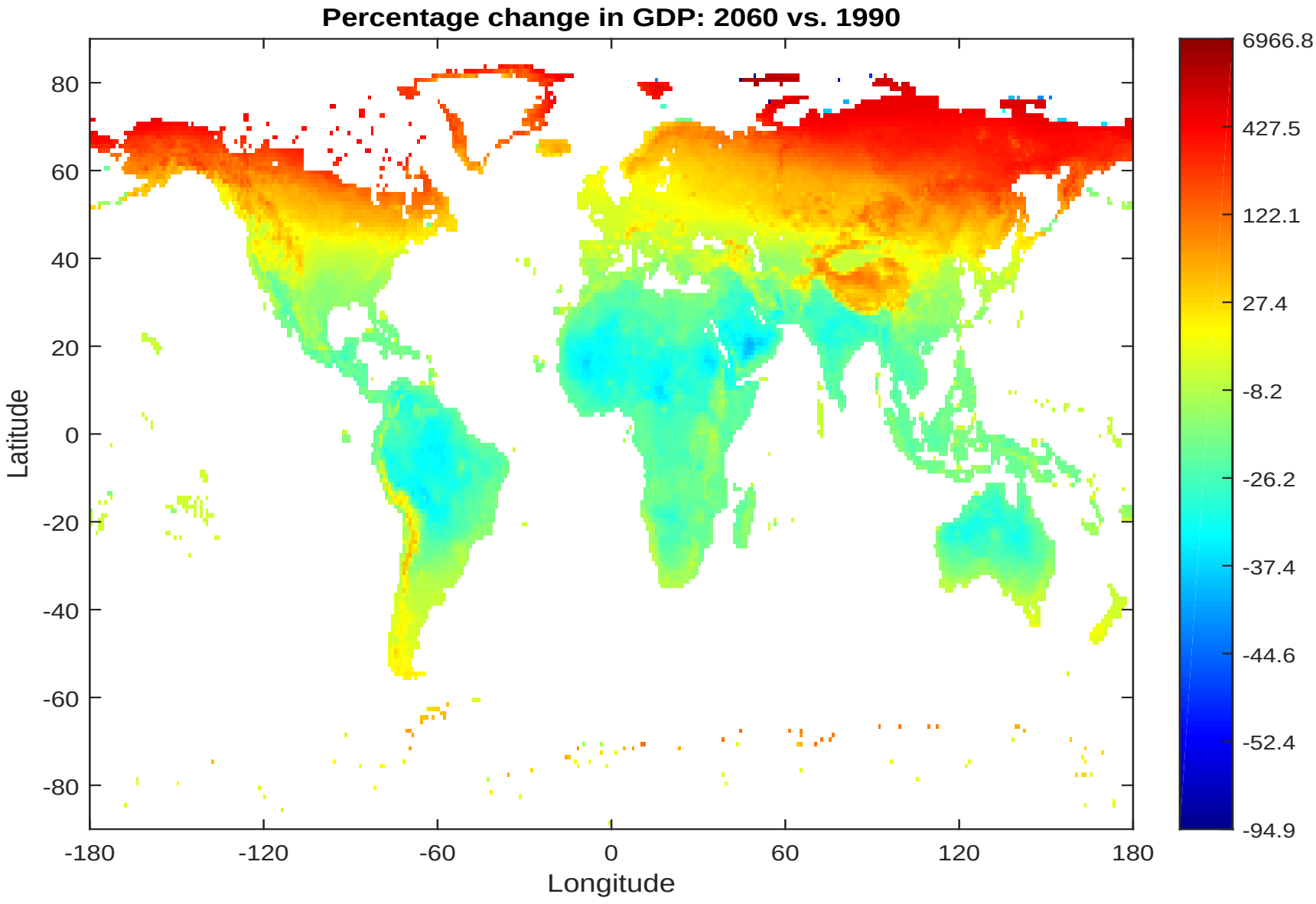

Percentage change in GDP: 2010 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

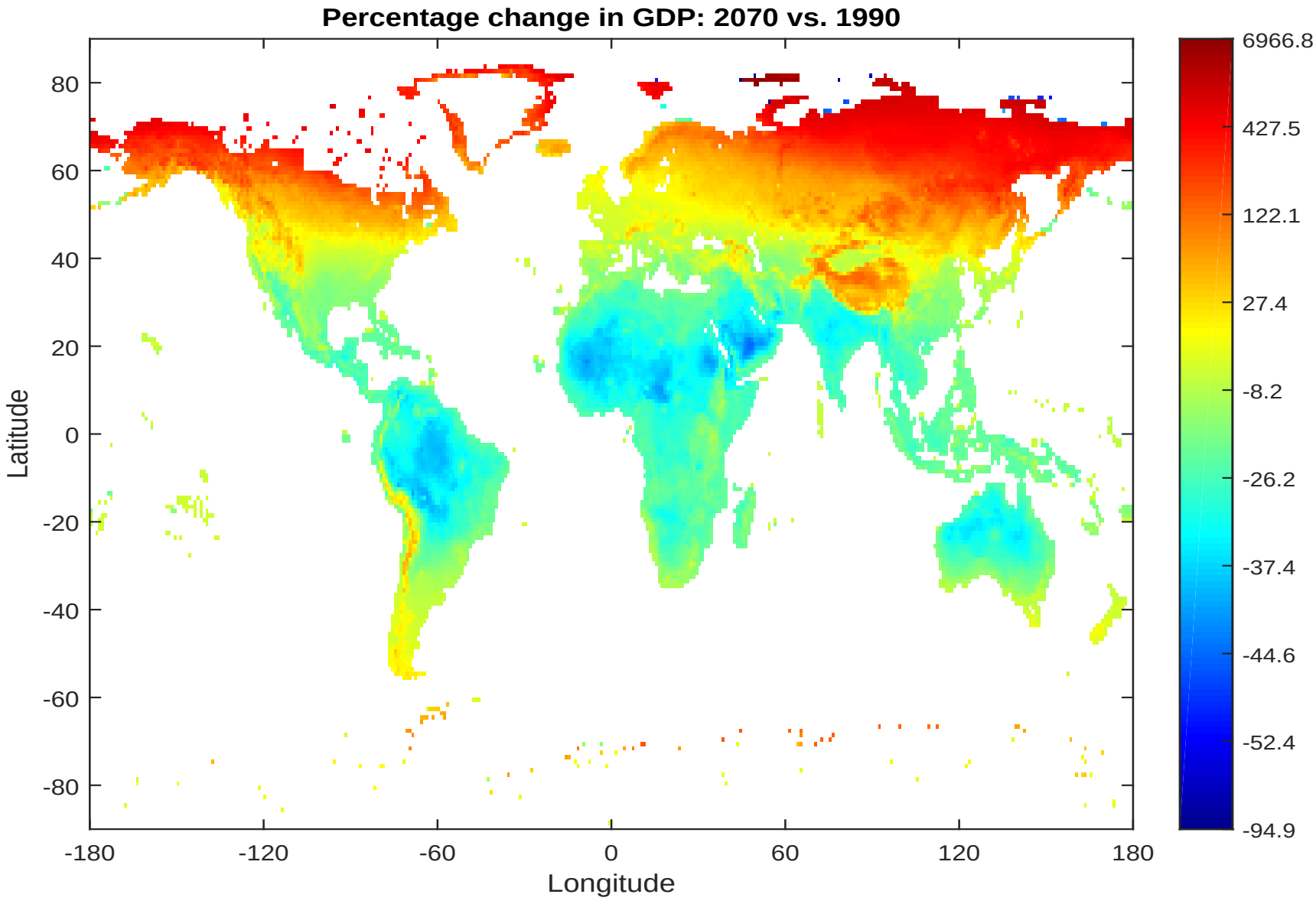

Percentage change in GDP: 2020 vs. 1990
Latitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
Longitude
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

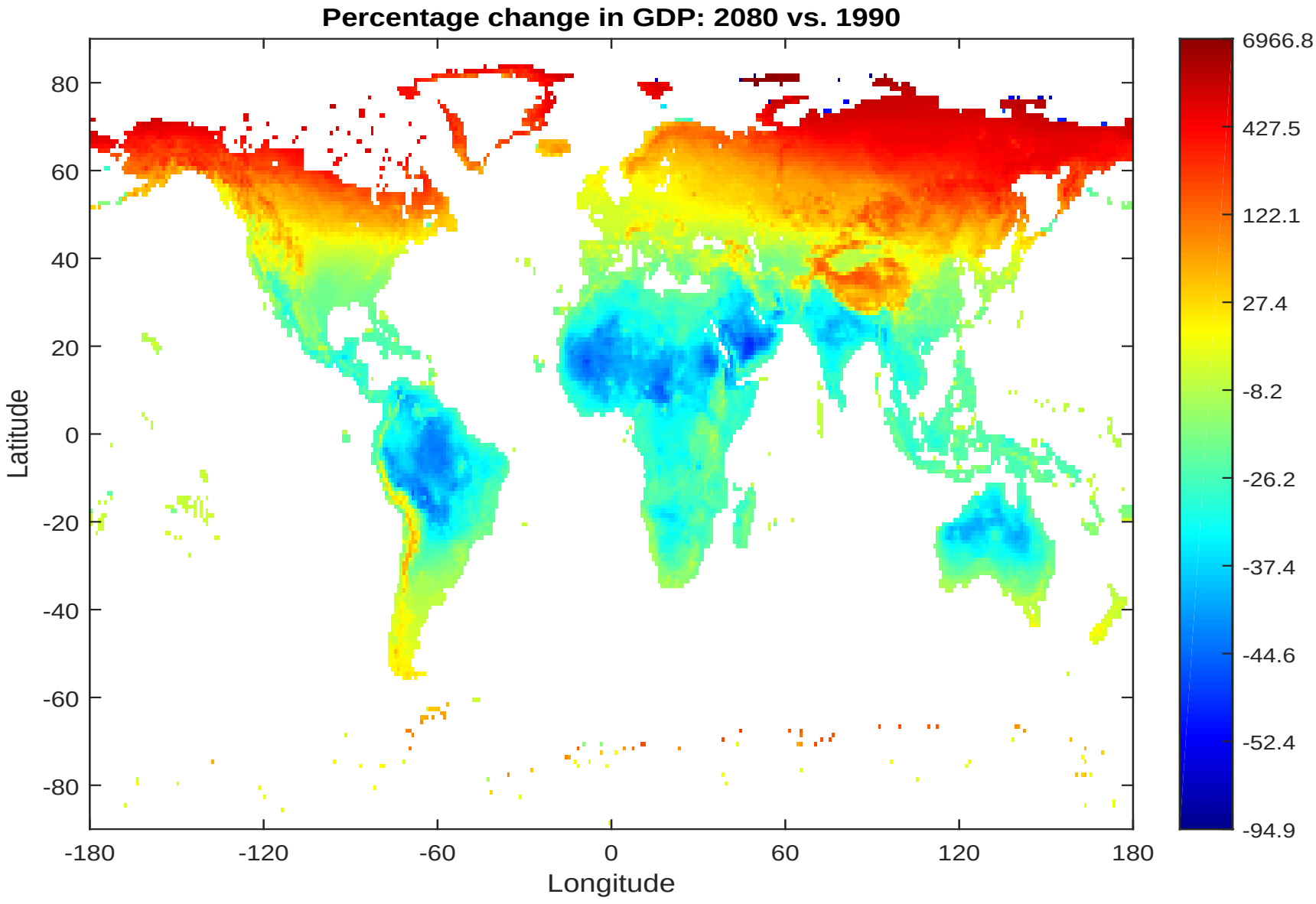

Percentage change in GDP: 2030 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

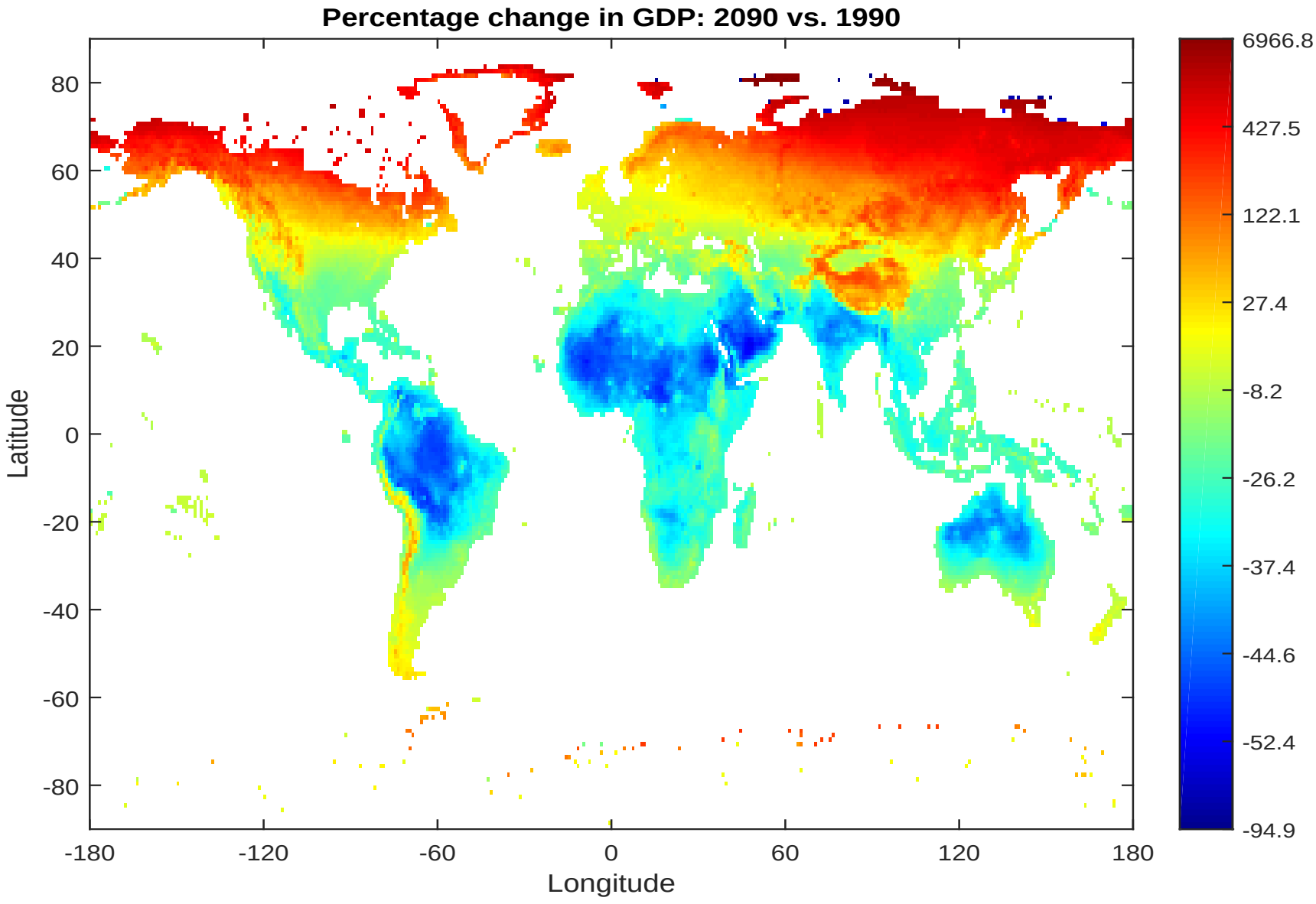

Percentage change in GDP: 2040 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


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
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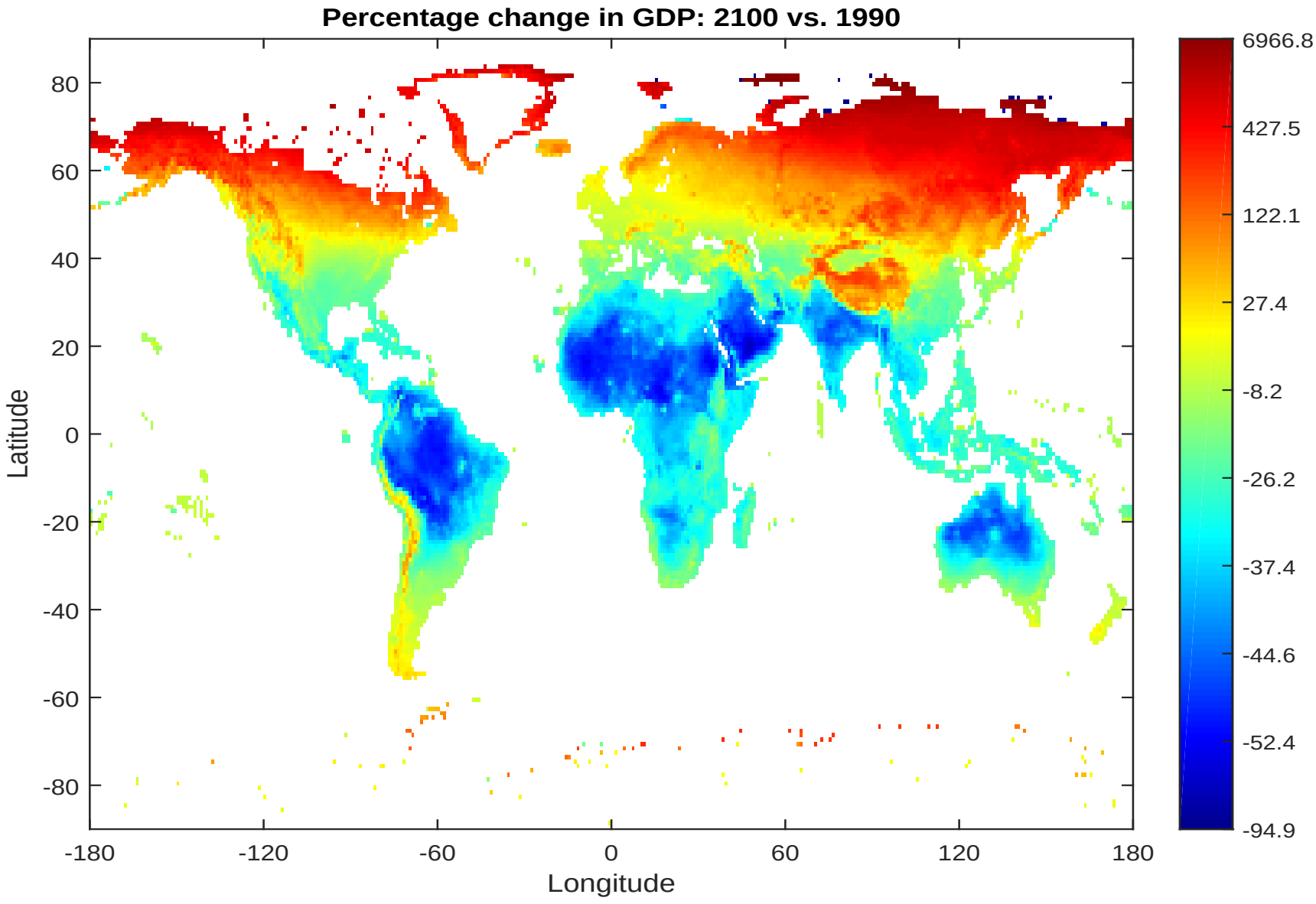
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


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
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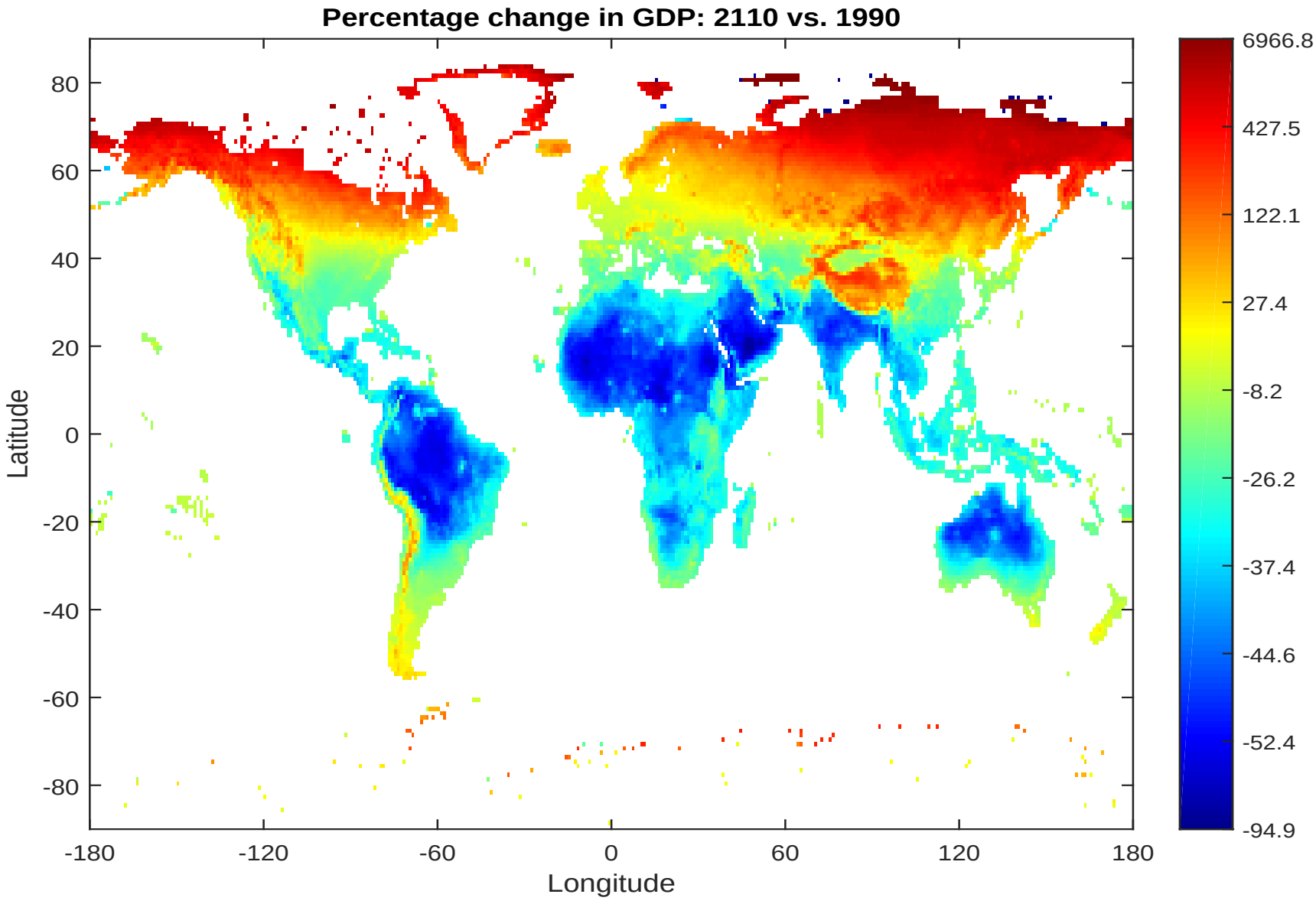
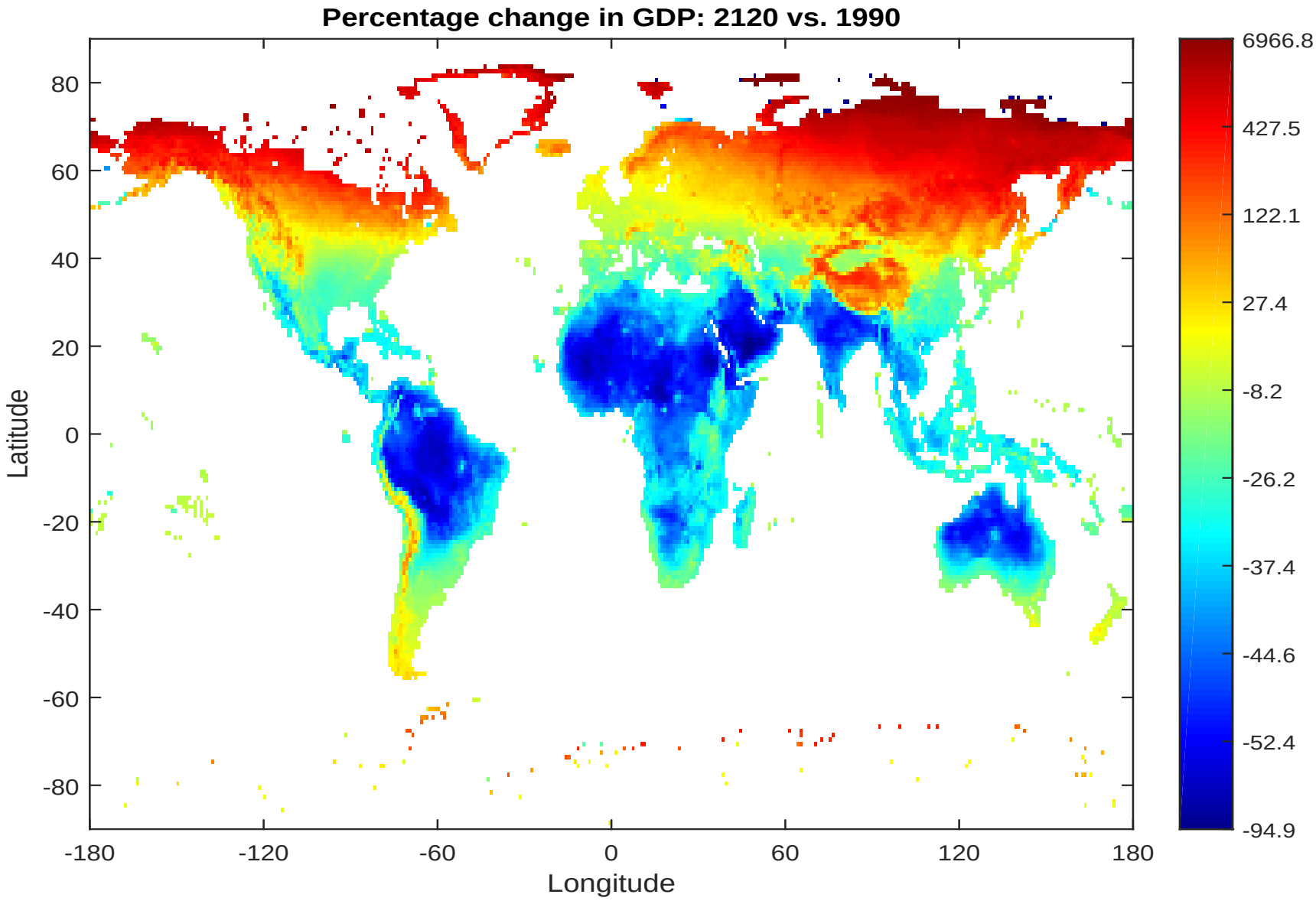
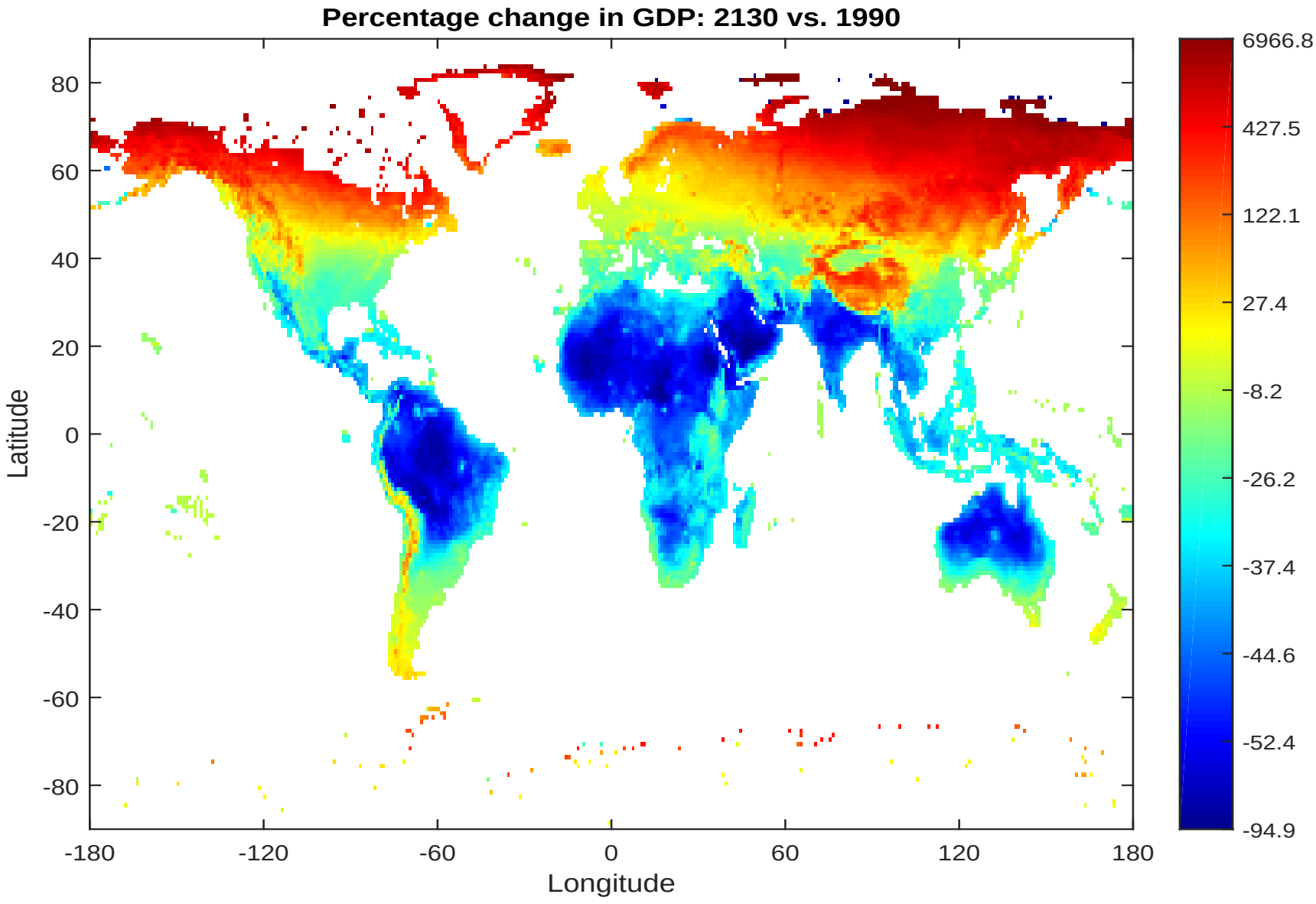
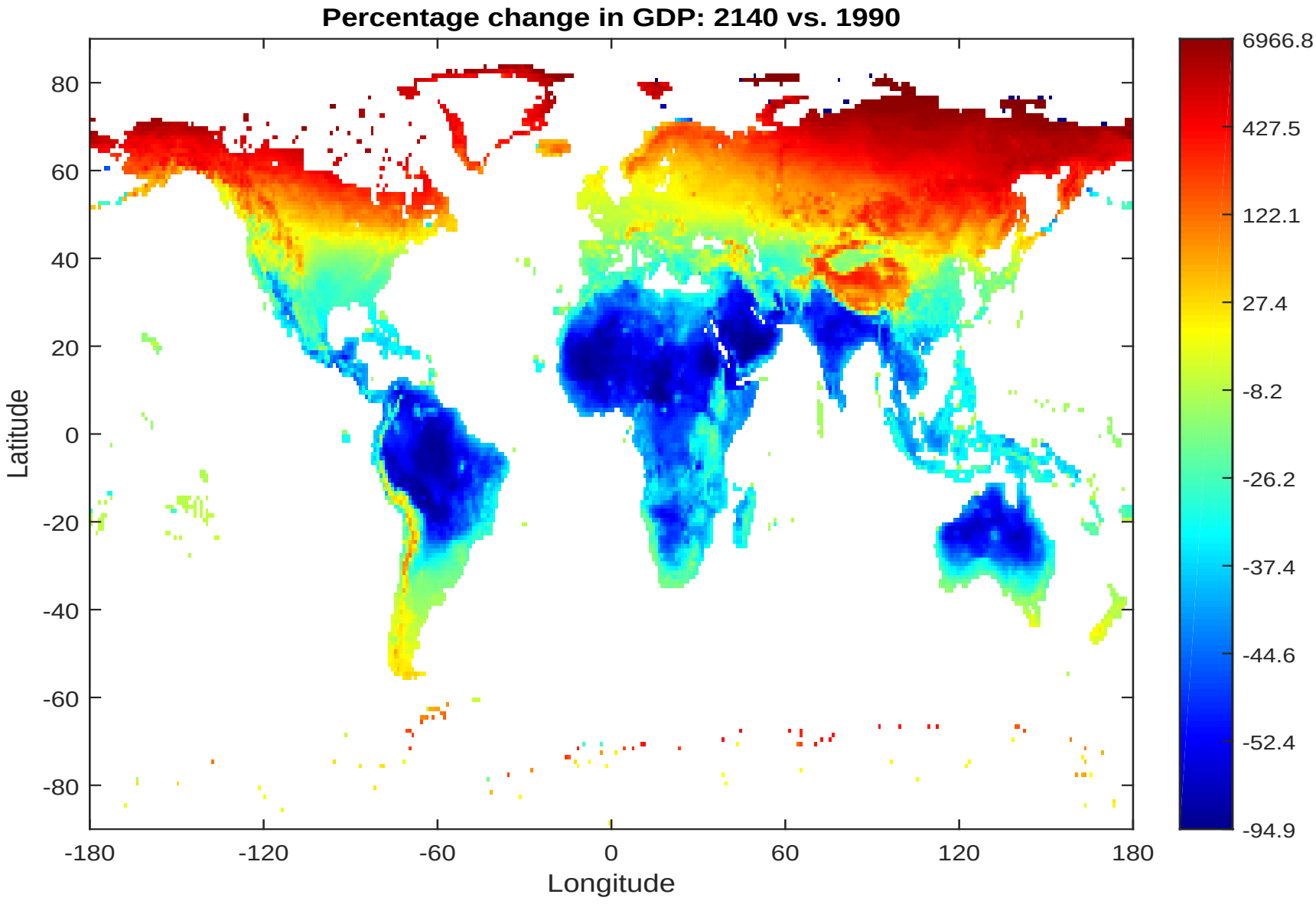
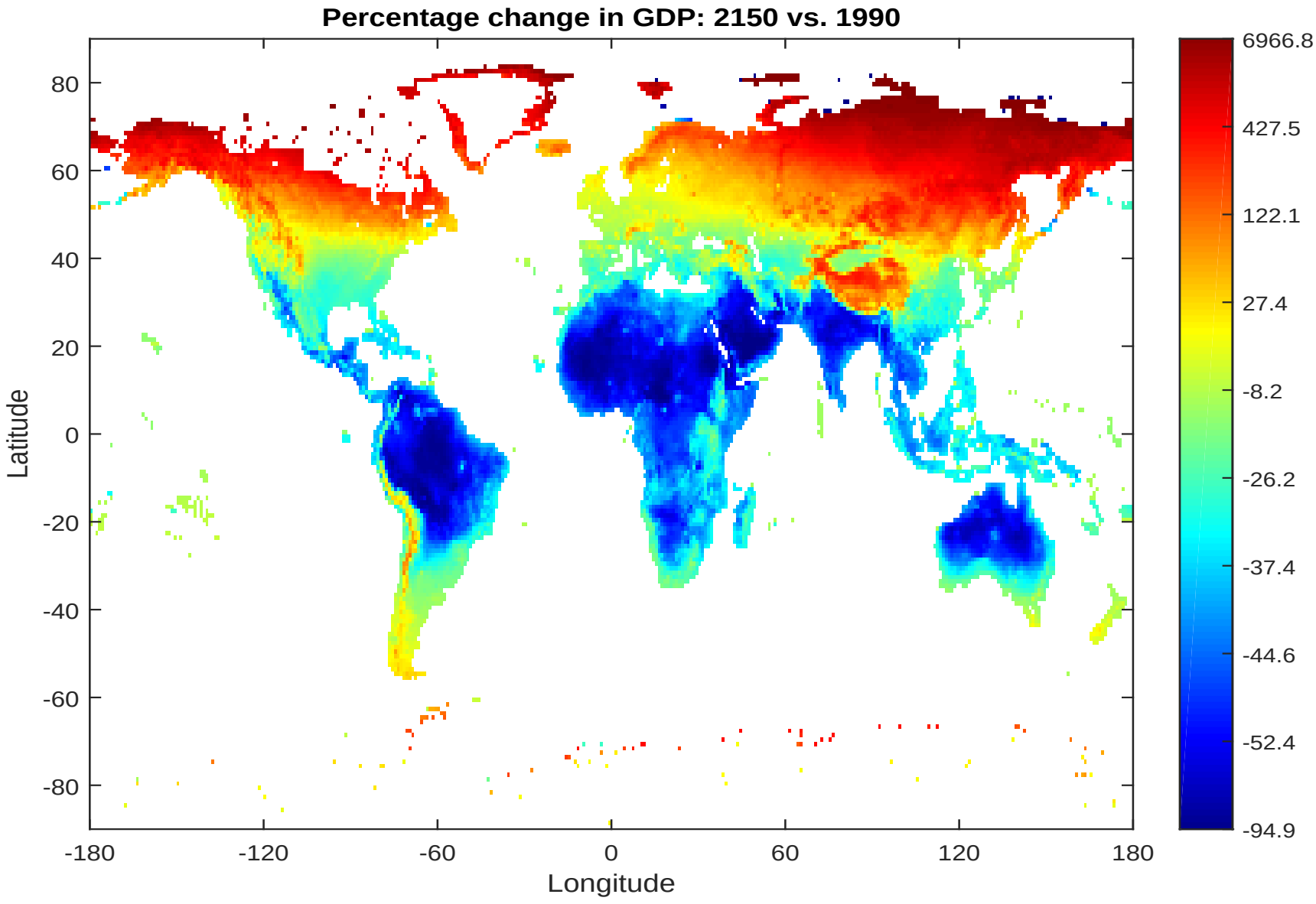
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


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
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: 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
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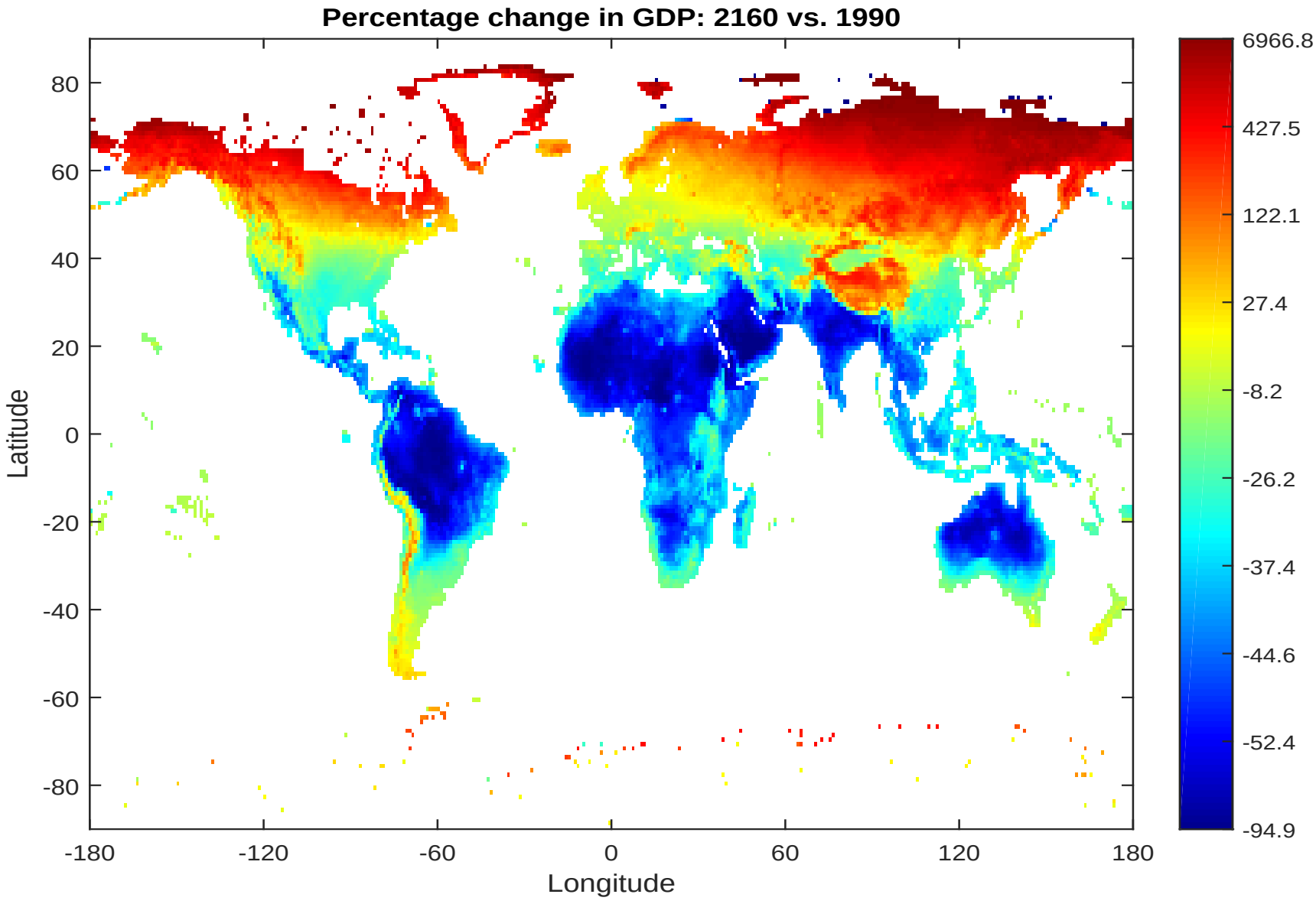
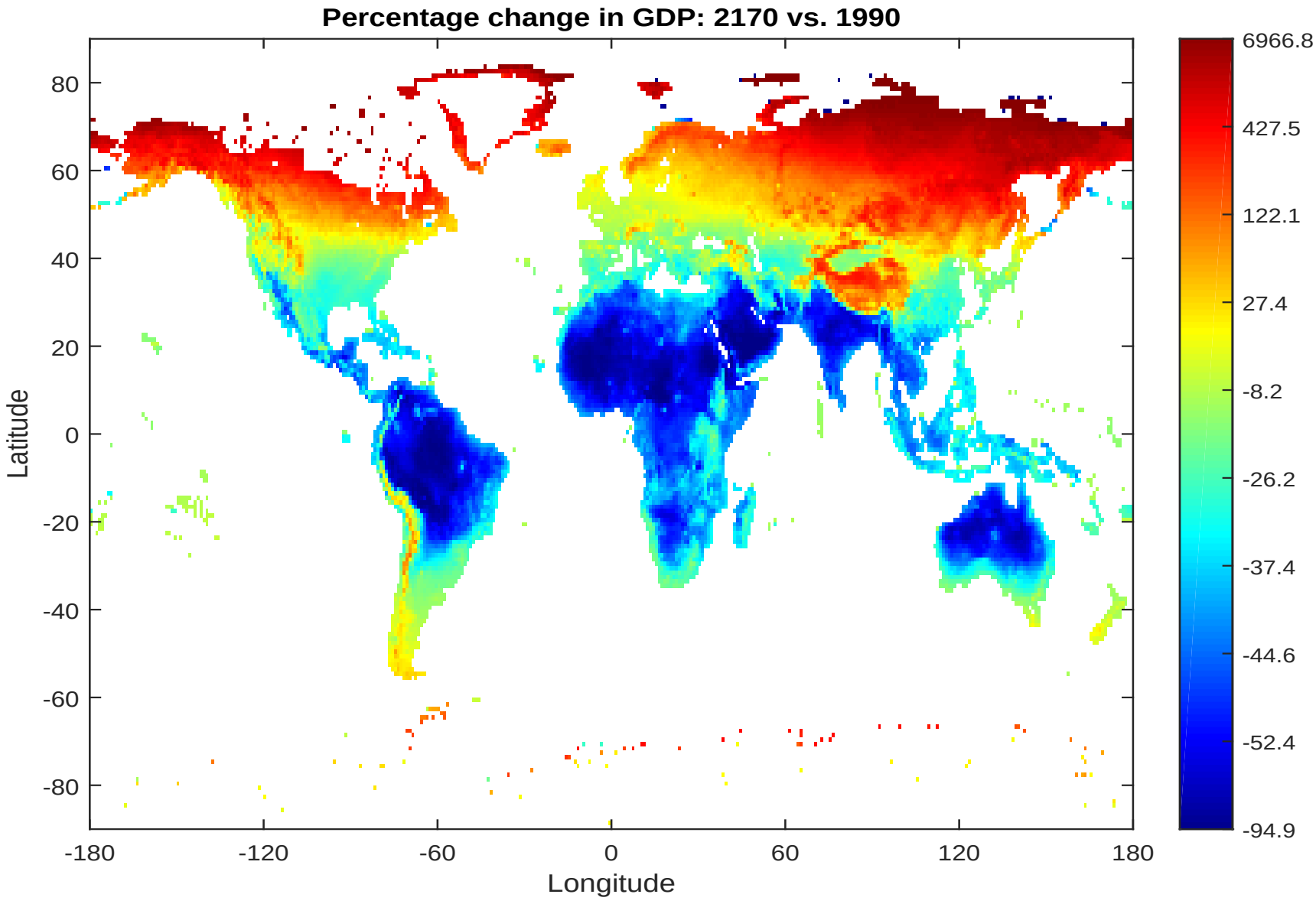
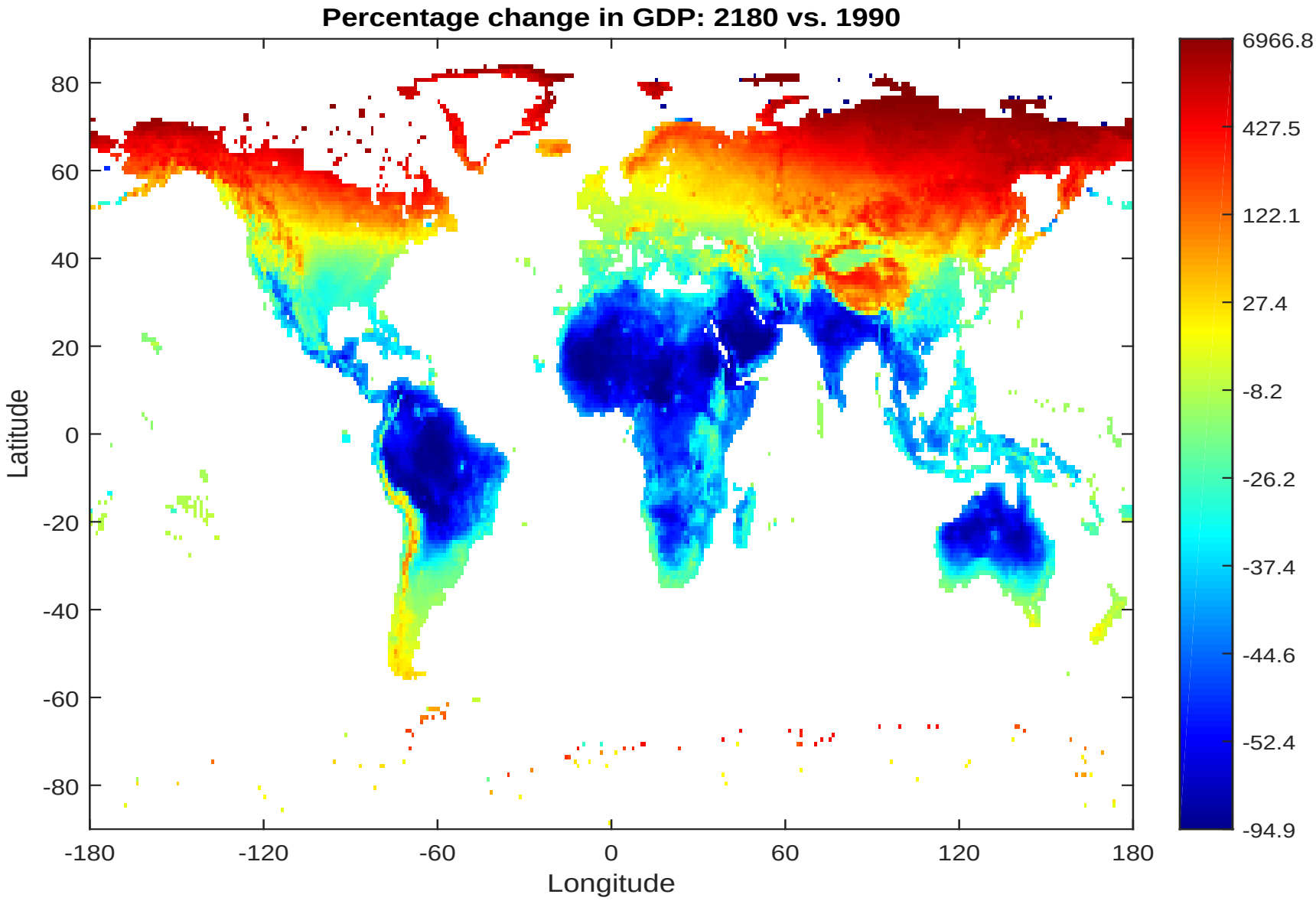
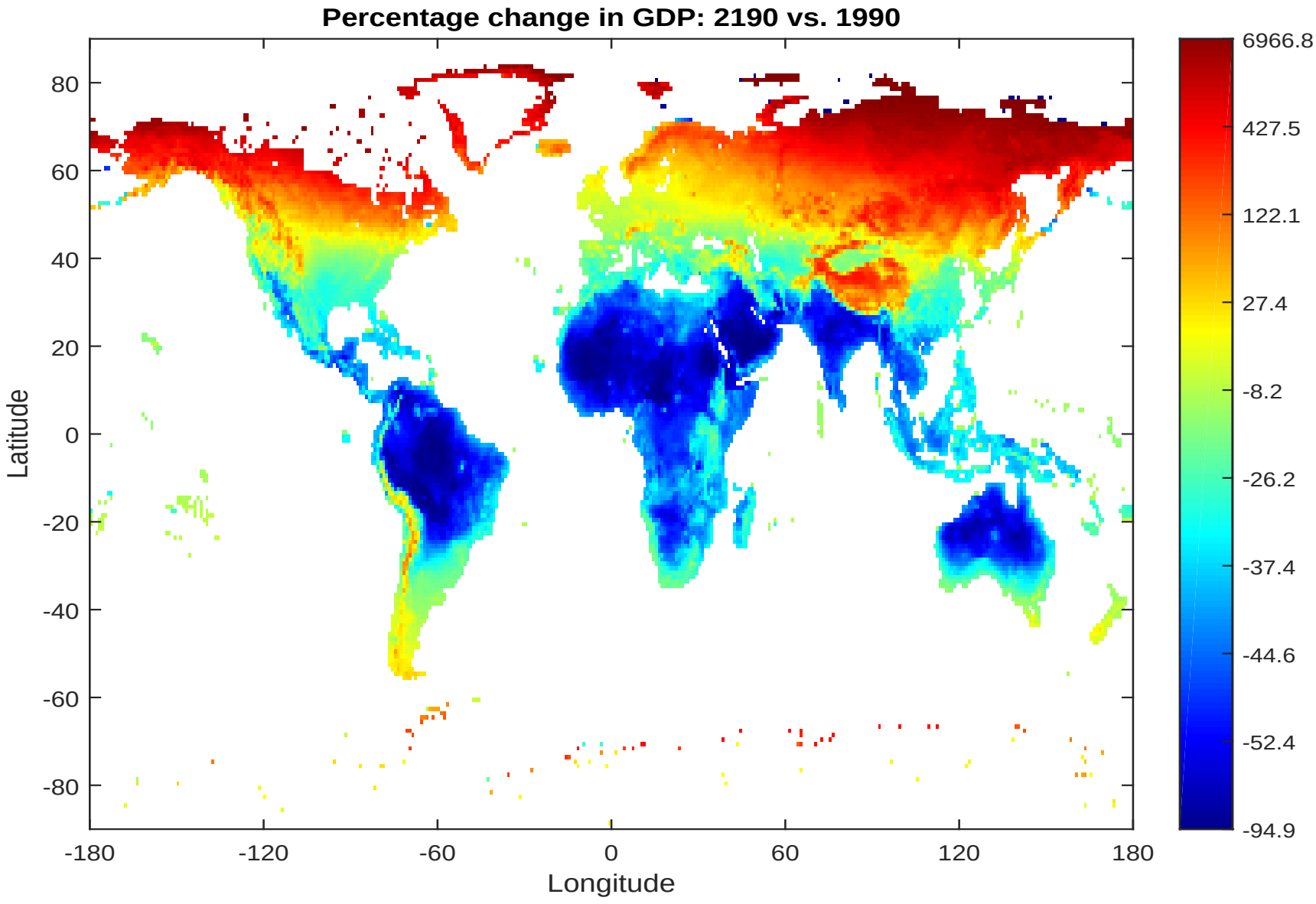
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9


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
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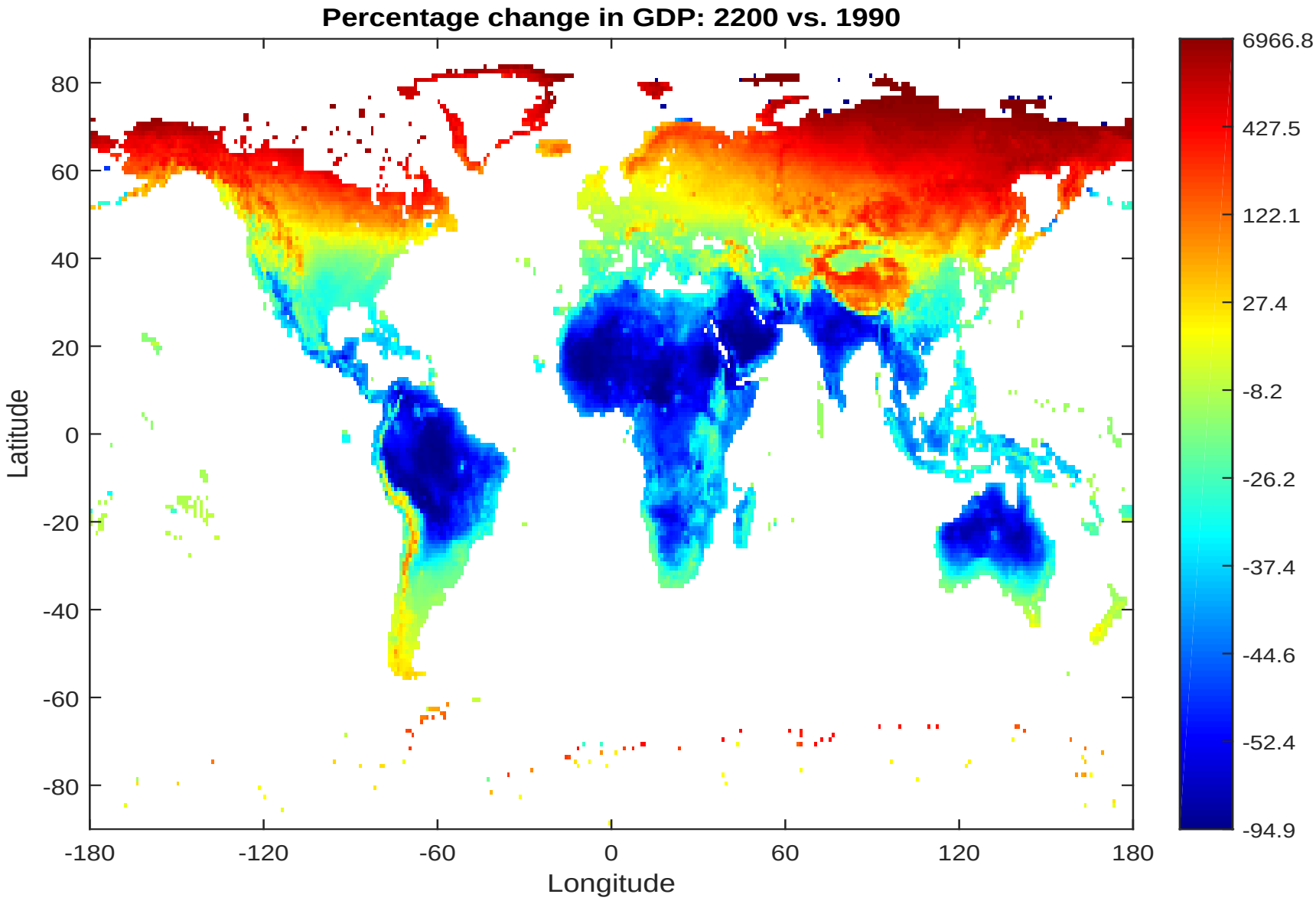
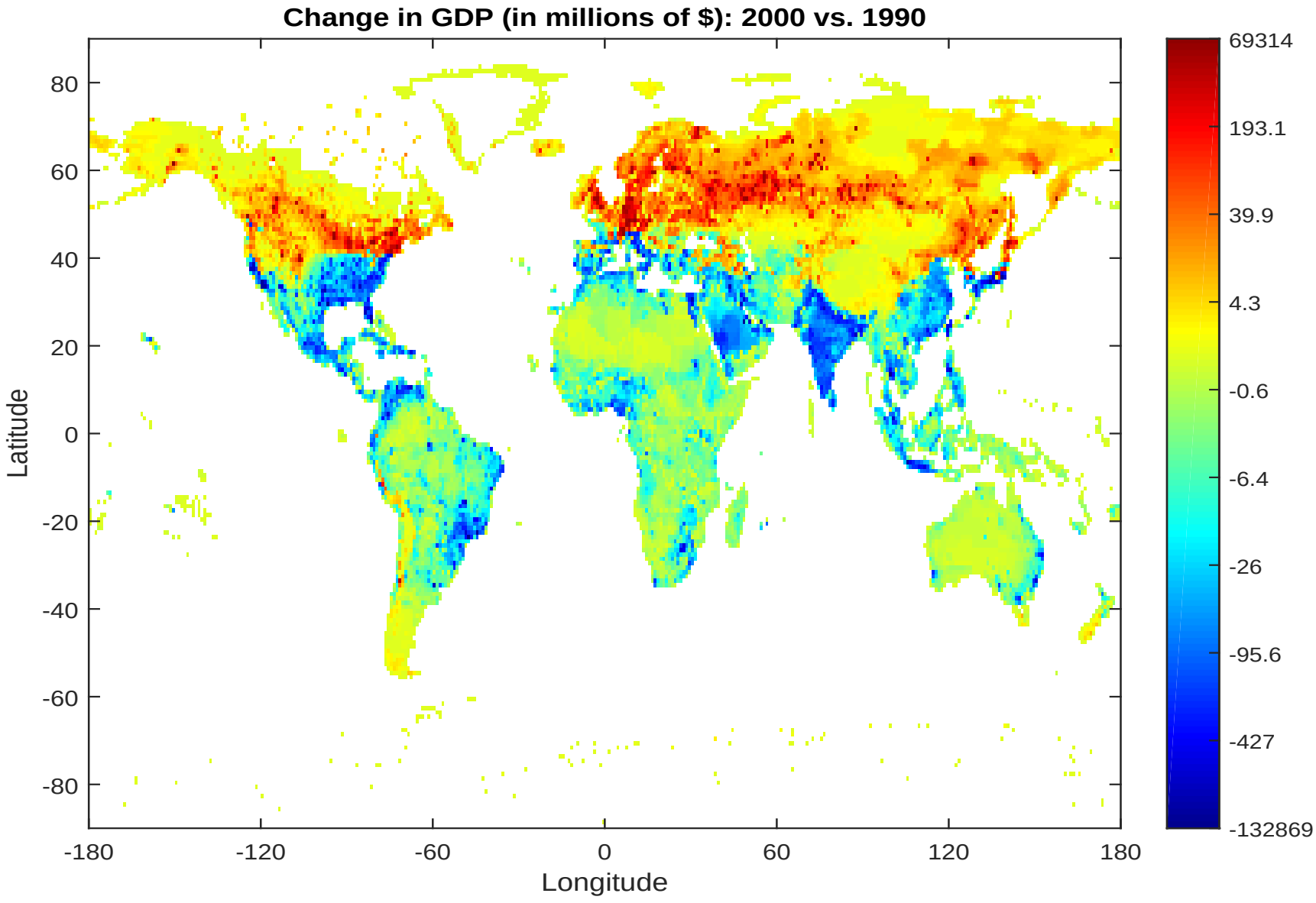
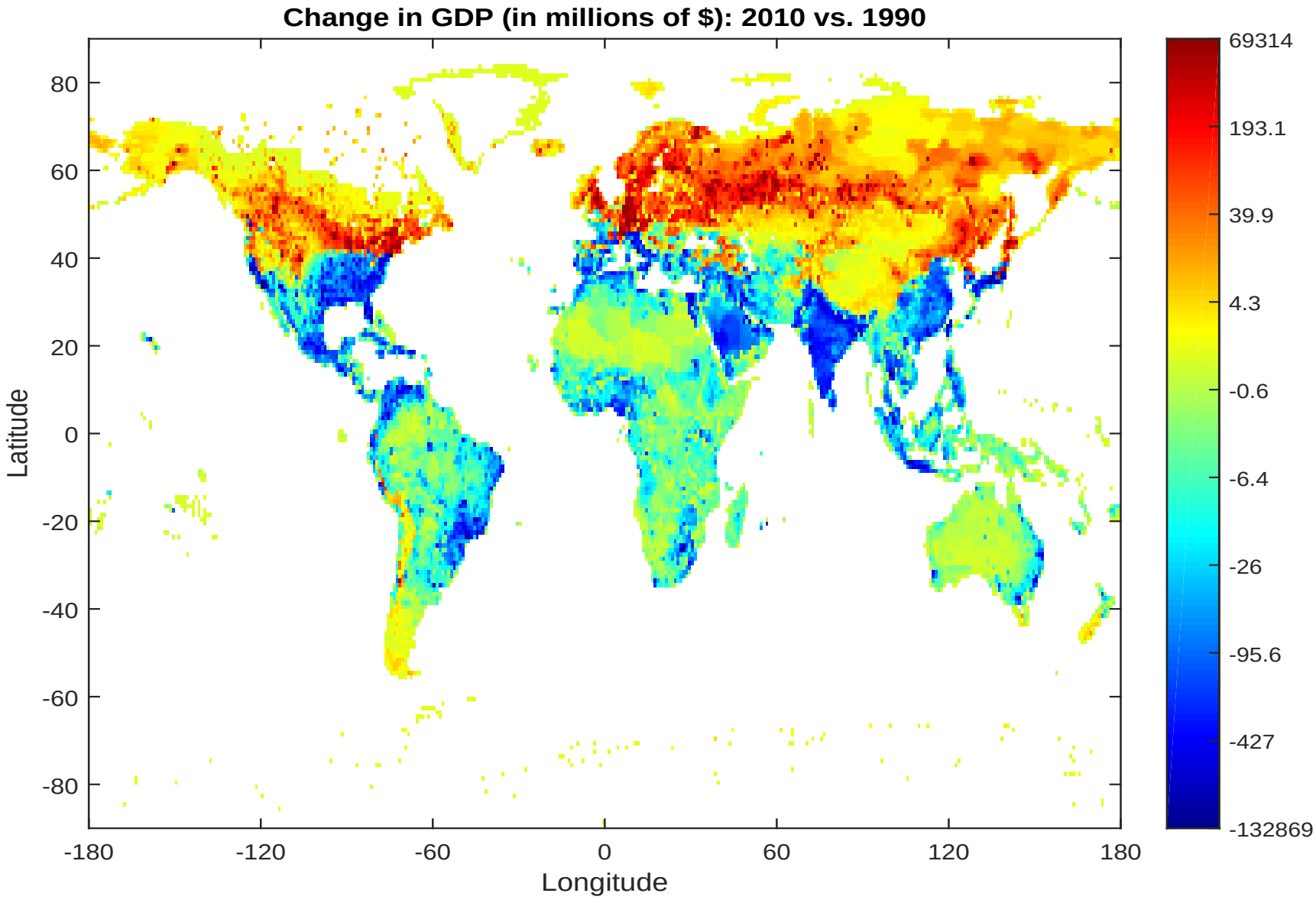
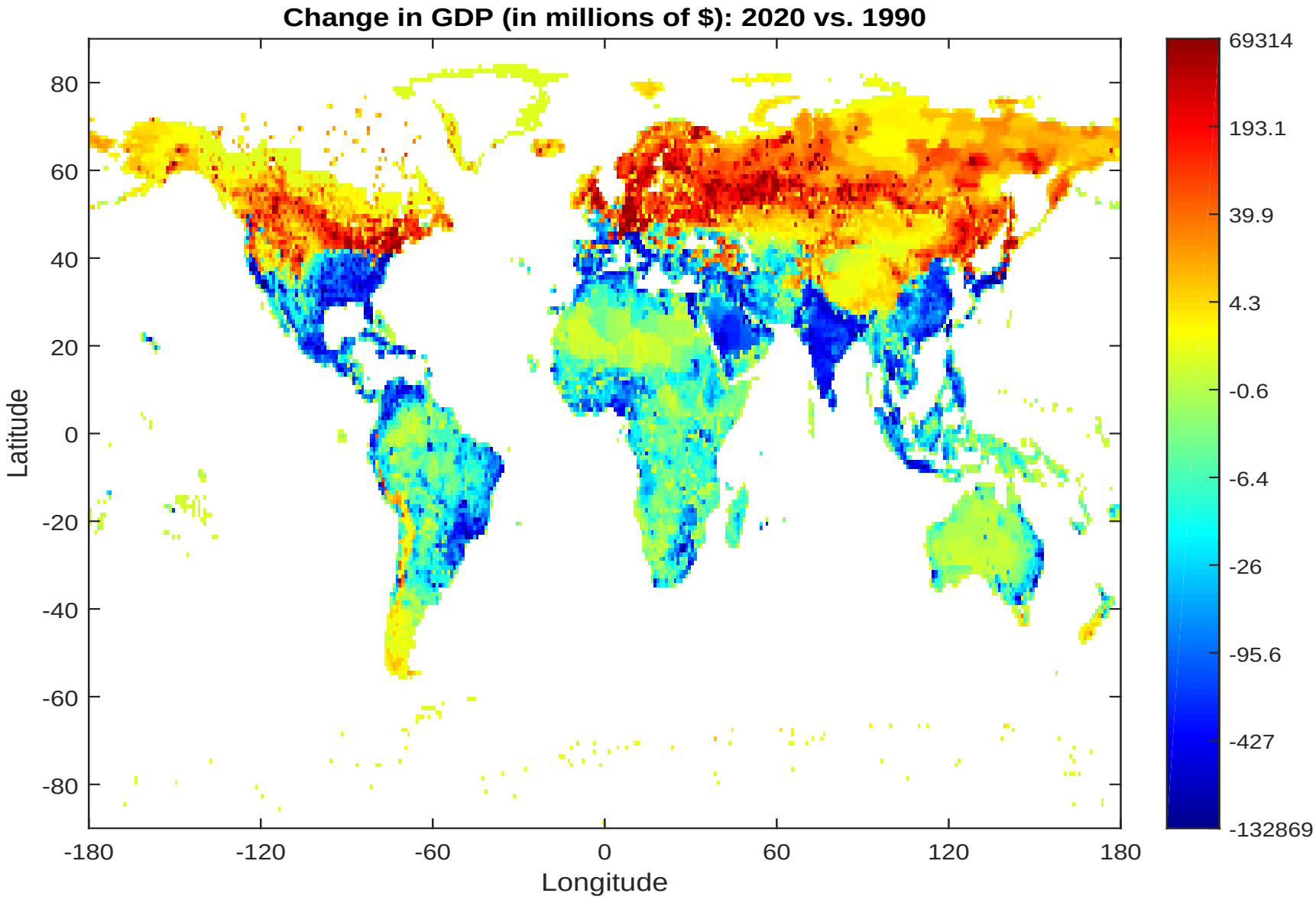
-26.2
-37.4
-44.6
-52.4
-94.9

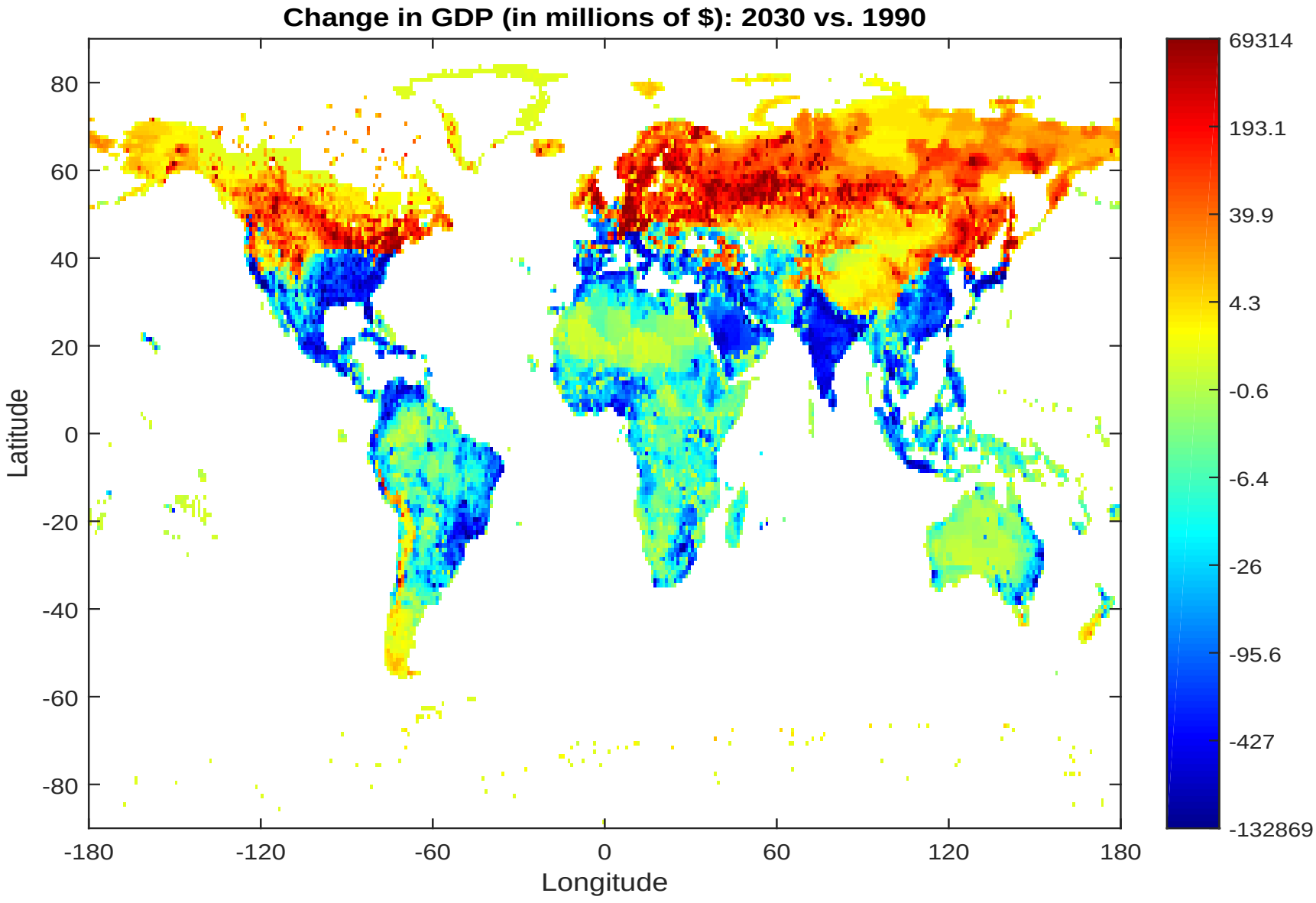

Percentage change in GDP: 2200 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
6966.8
427.5
122.1
27.4
-8.2
-26.2
-37.4
-44.6
-52.4
-94.9

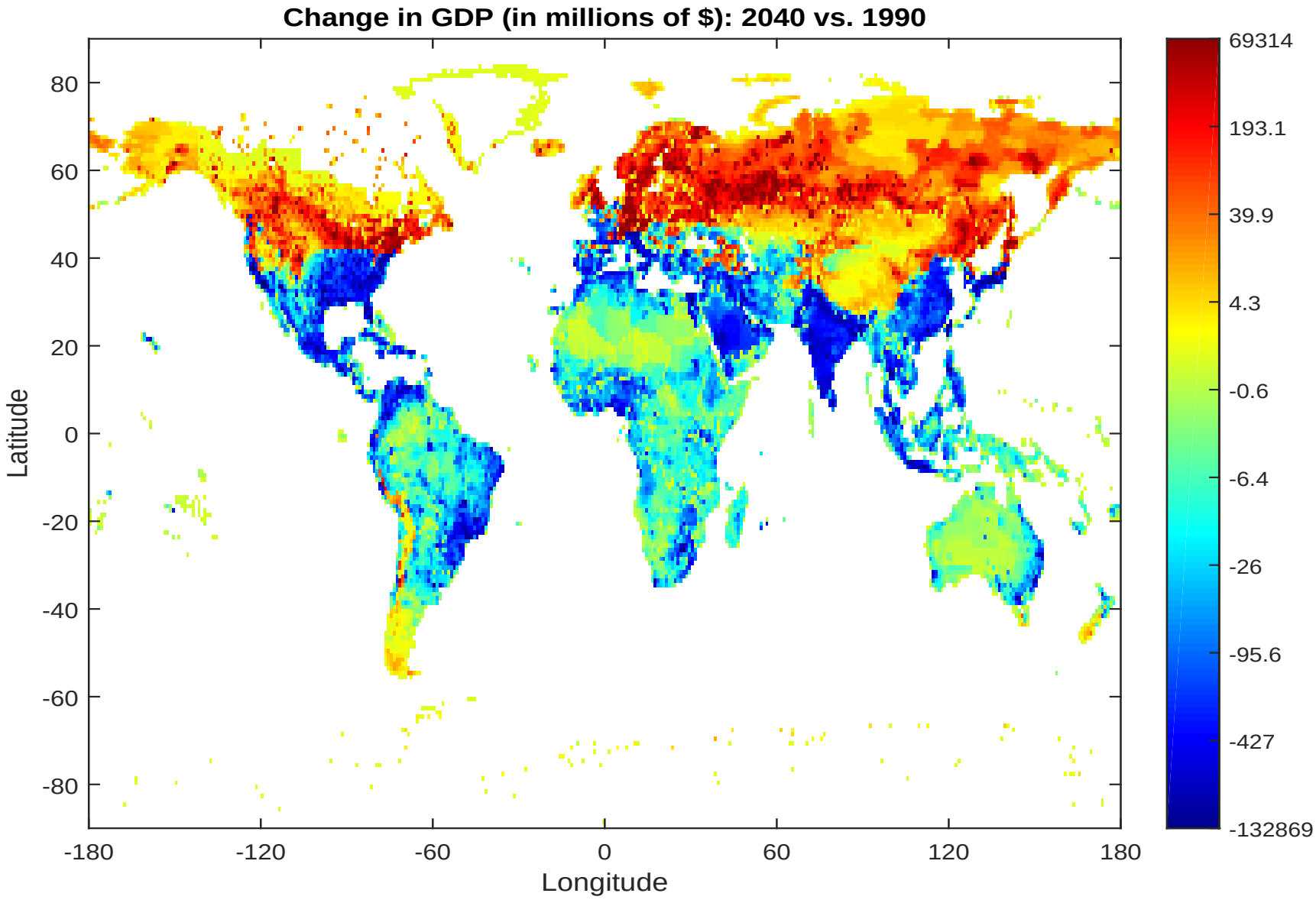
movie: level change in gdp, laissez-faire

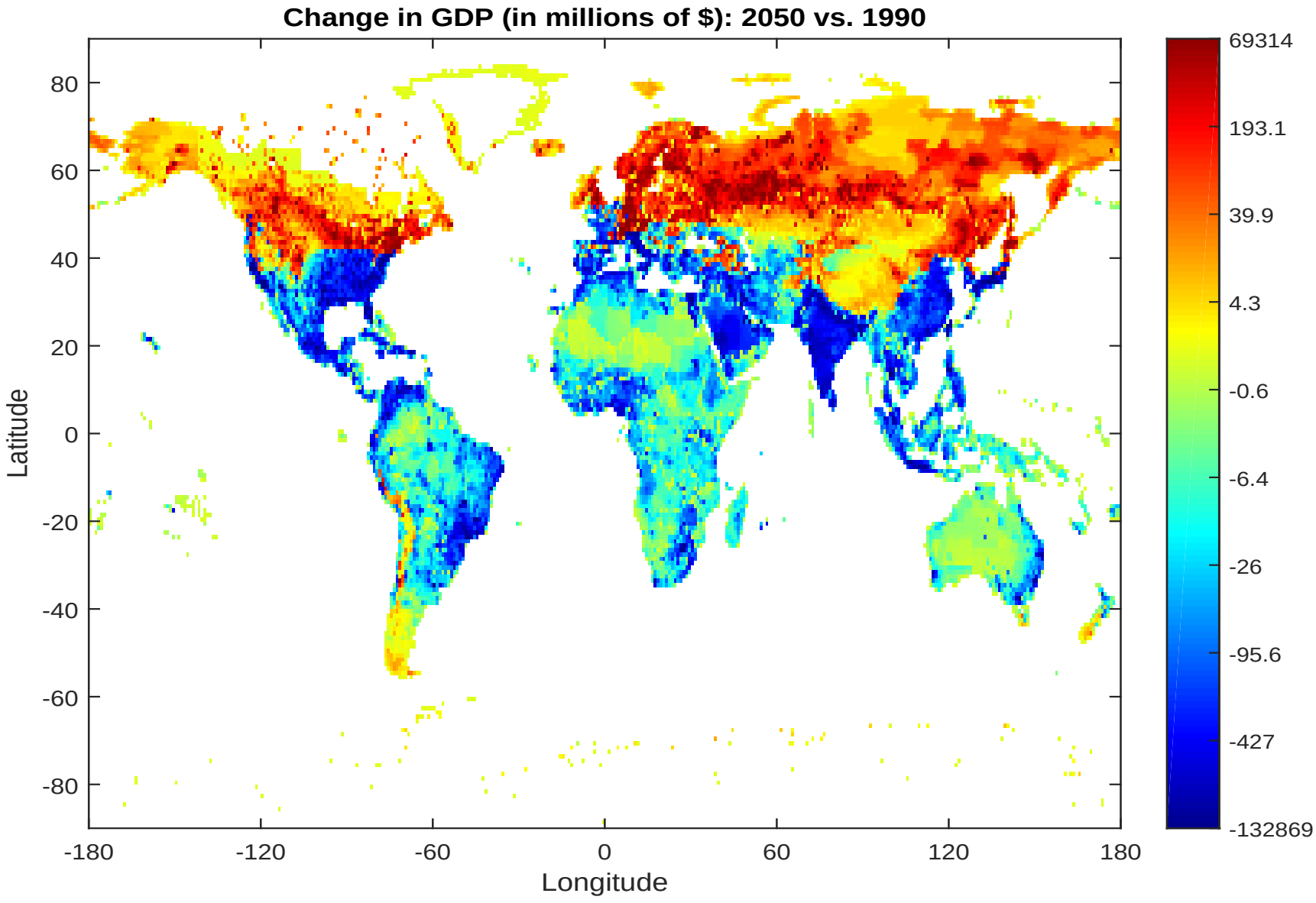

Change in GDP (in millions of $): 2000 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

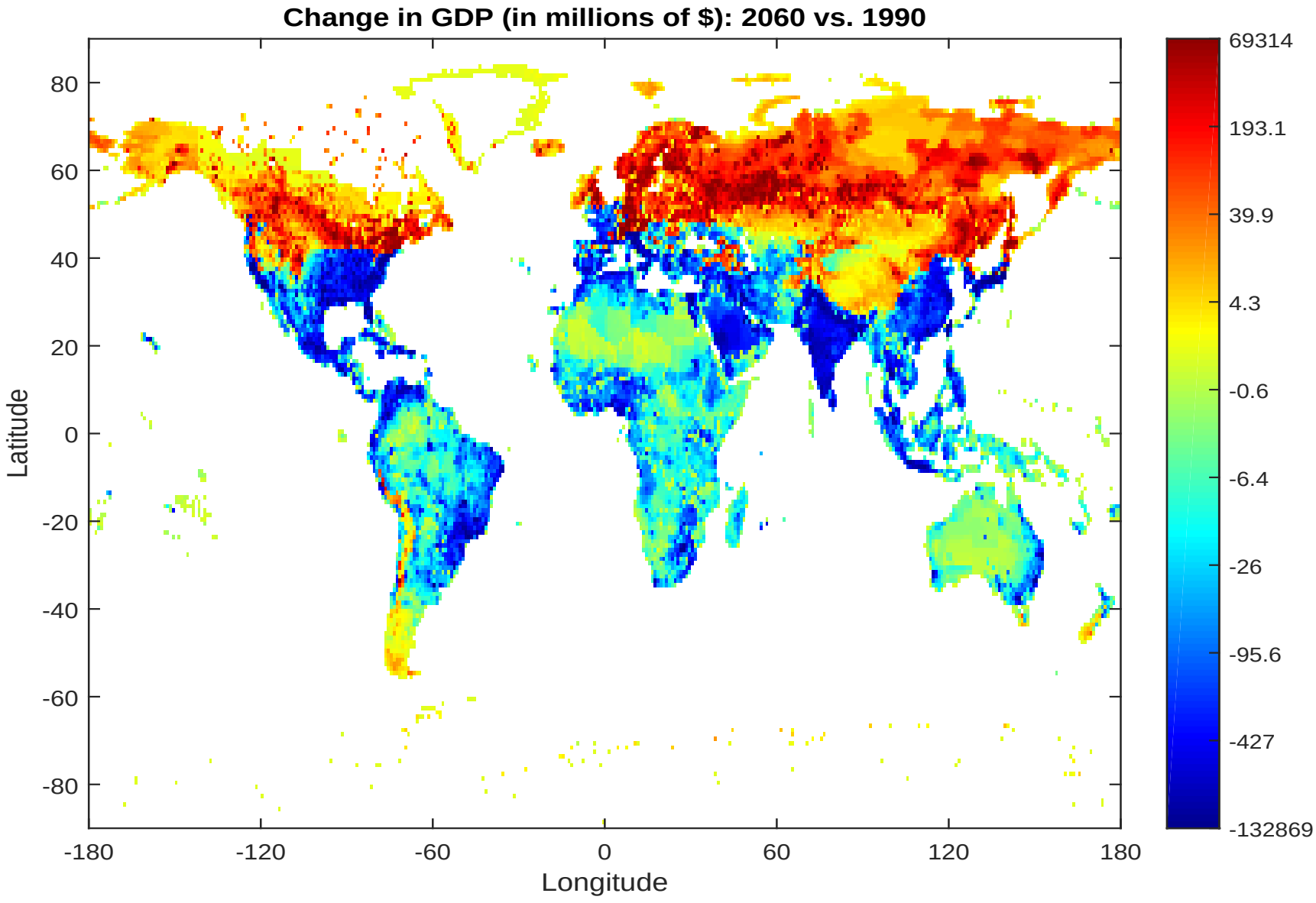

Change in GDP (in millions of $): 2010 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

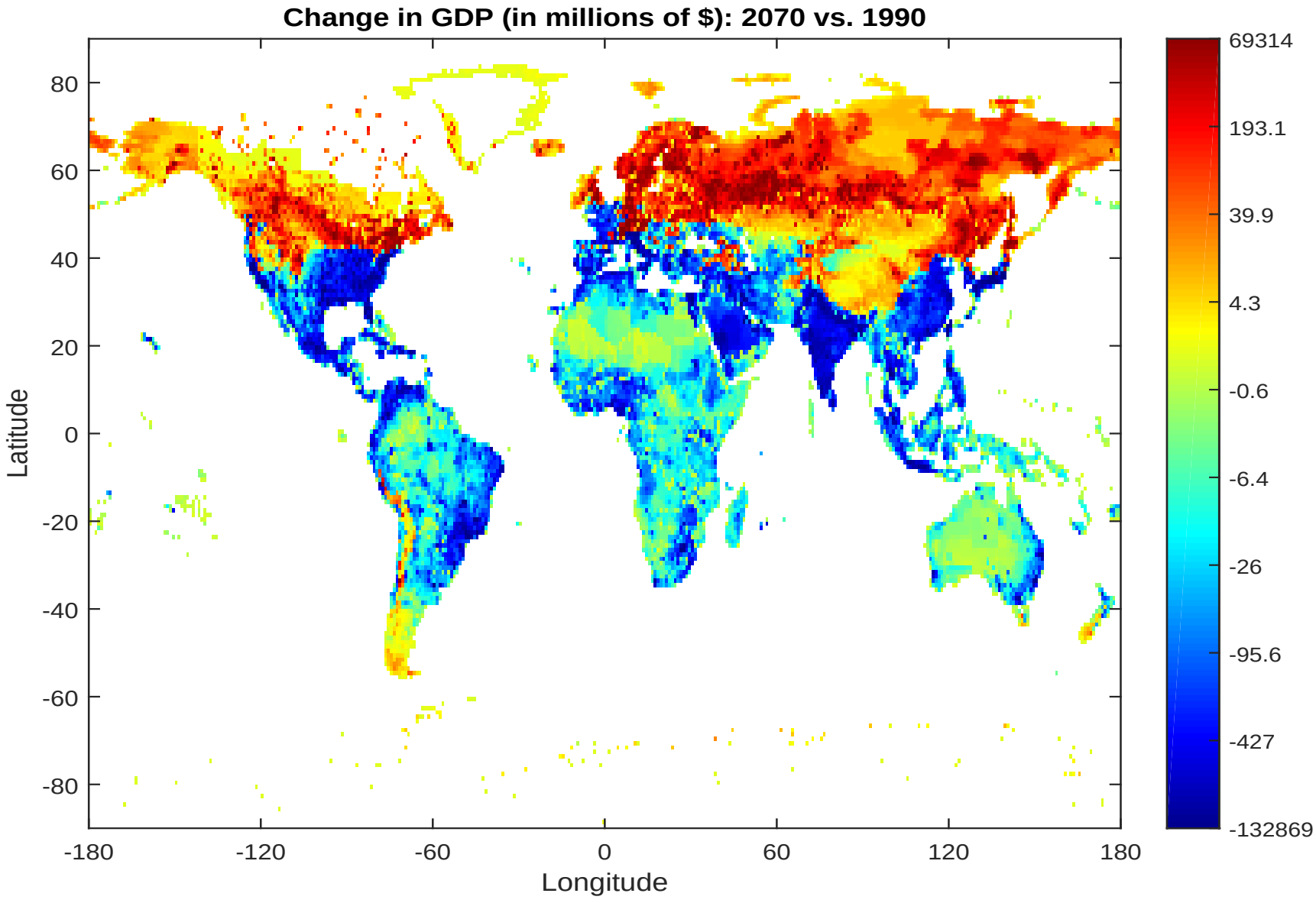

Change in GDP (in millions of $): 2020 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

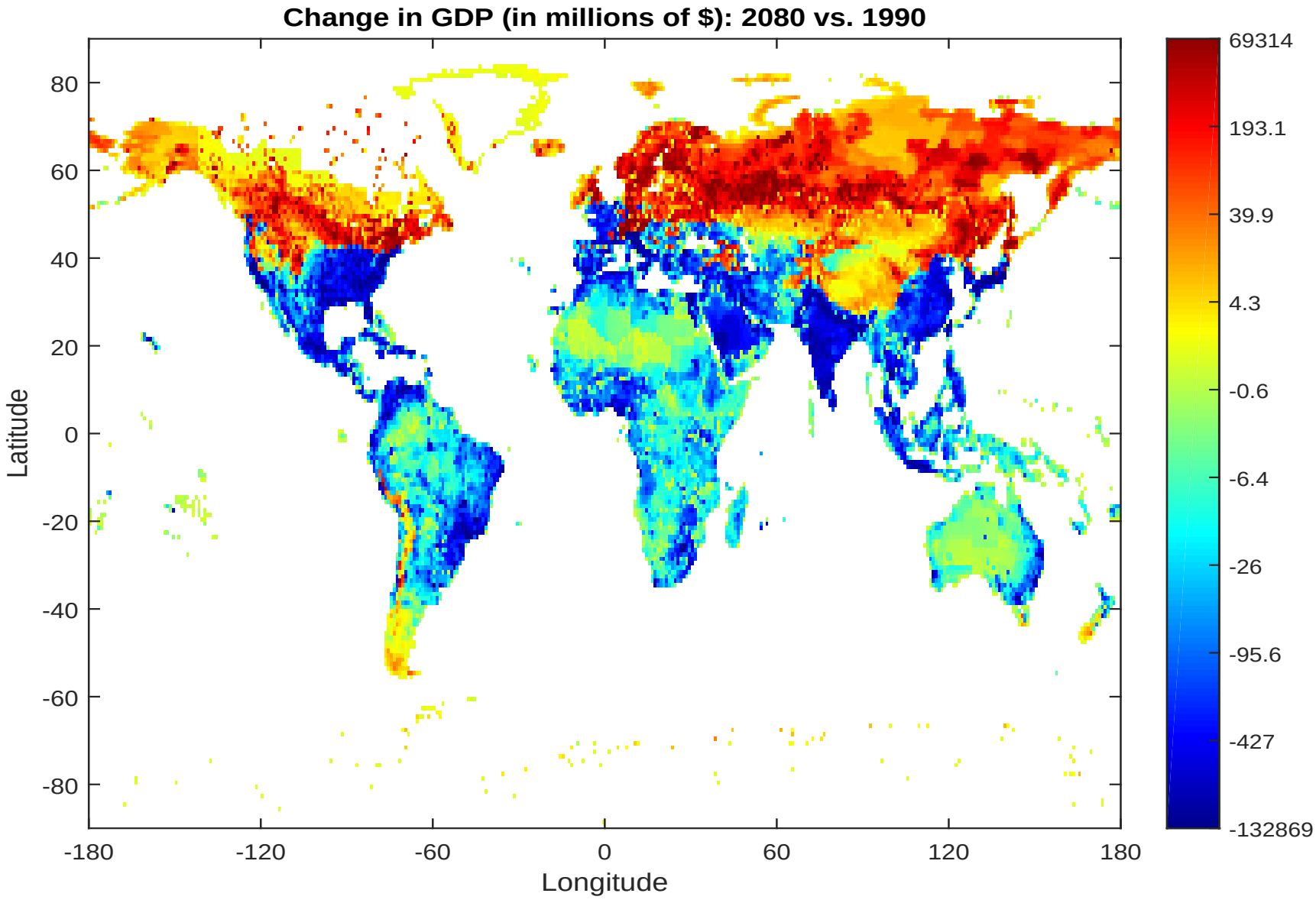

Change in GDP (in millions of $): 2030 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

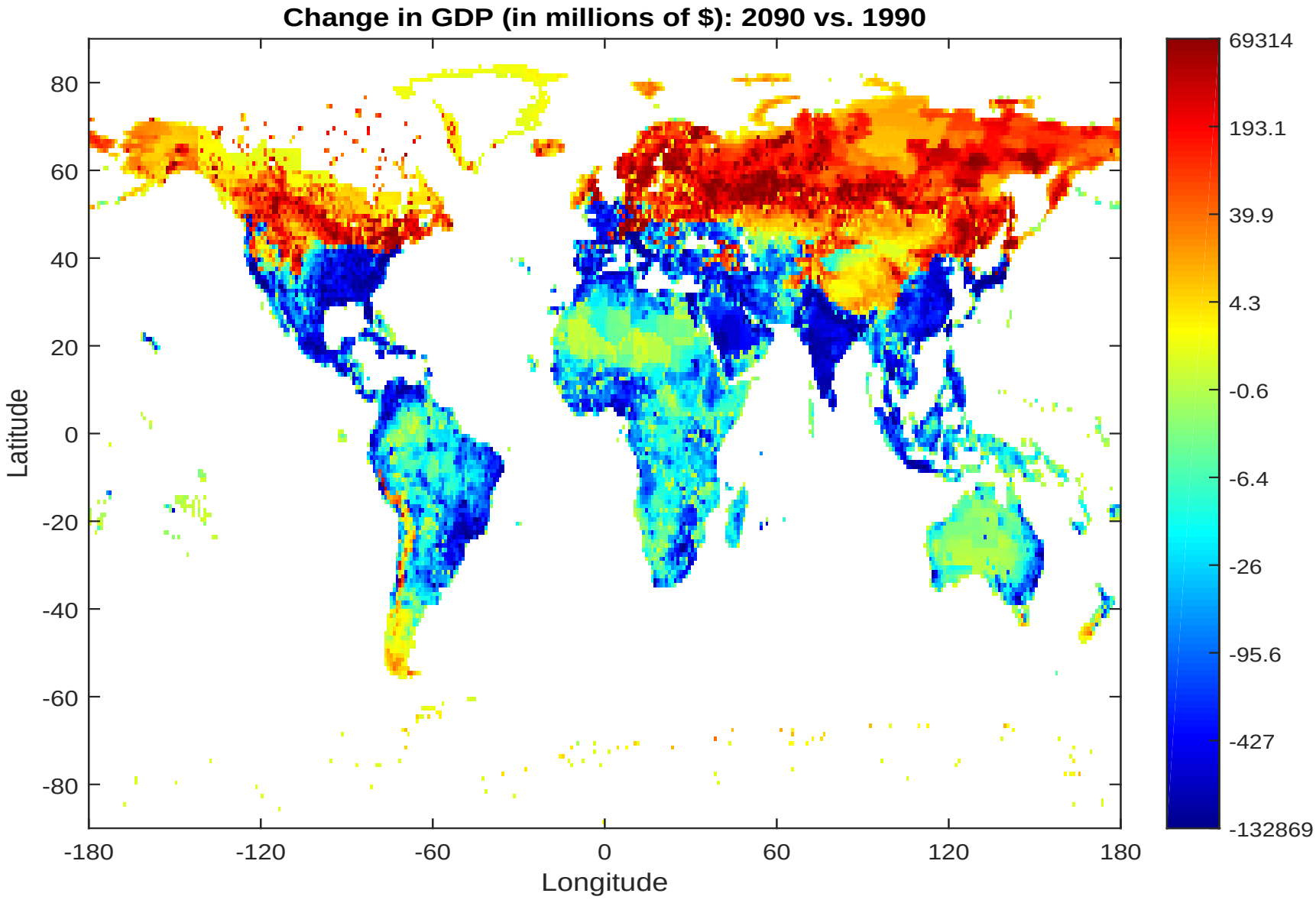

Change in GDP (in millions of $): 2040 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

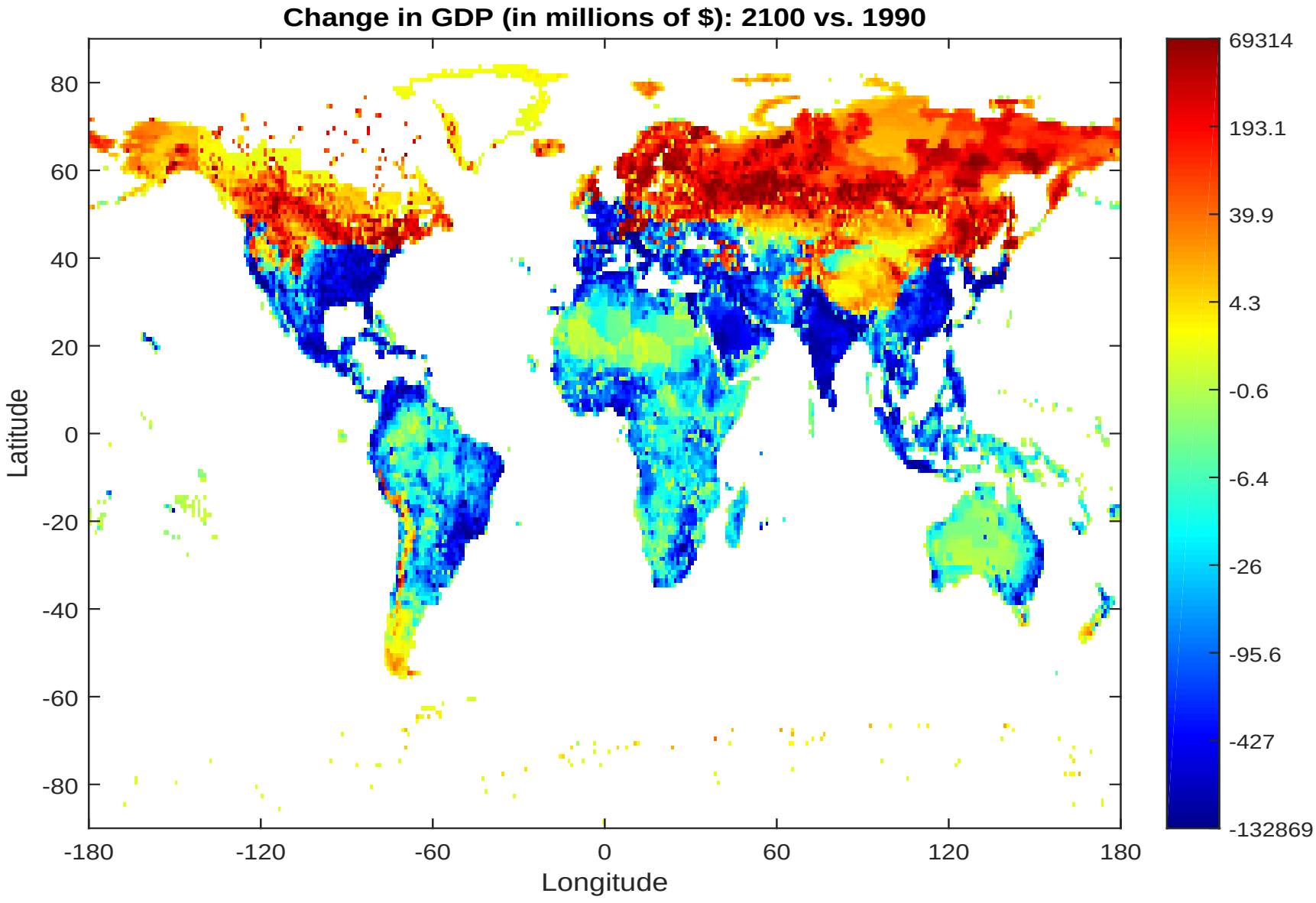

Change in GDP (in millions of $): 2050 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

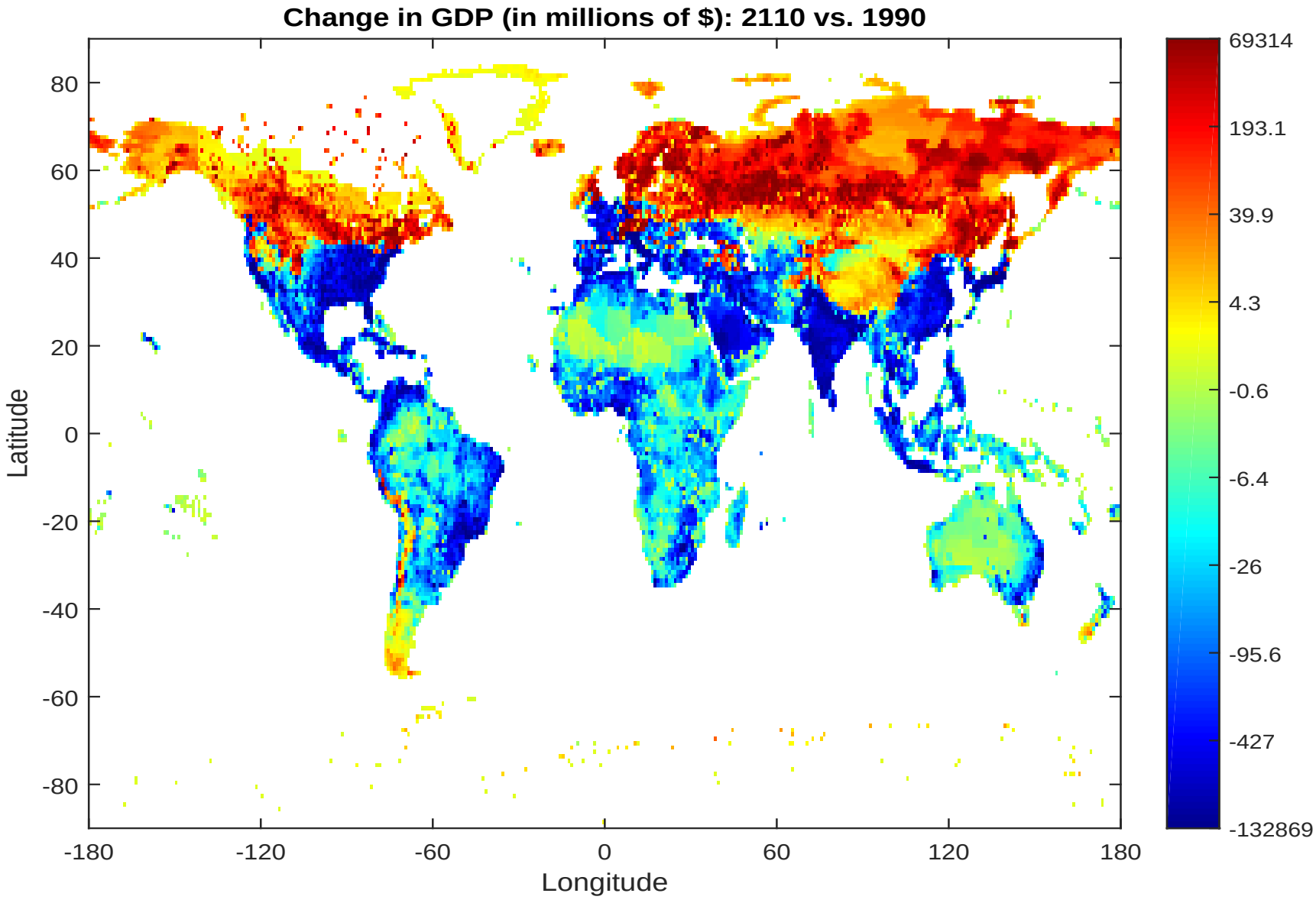

Change in GDP (in millions of $): 2060 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

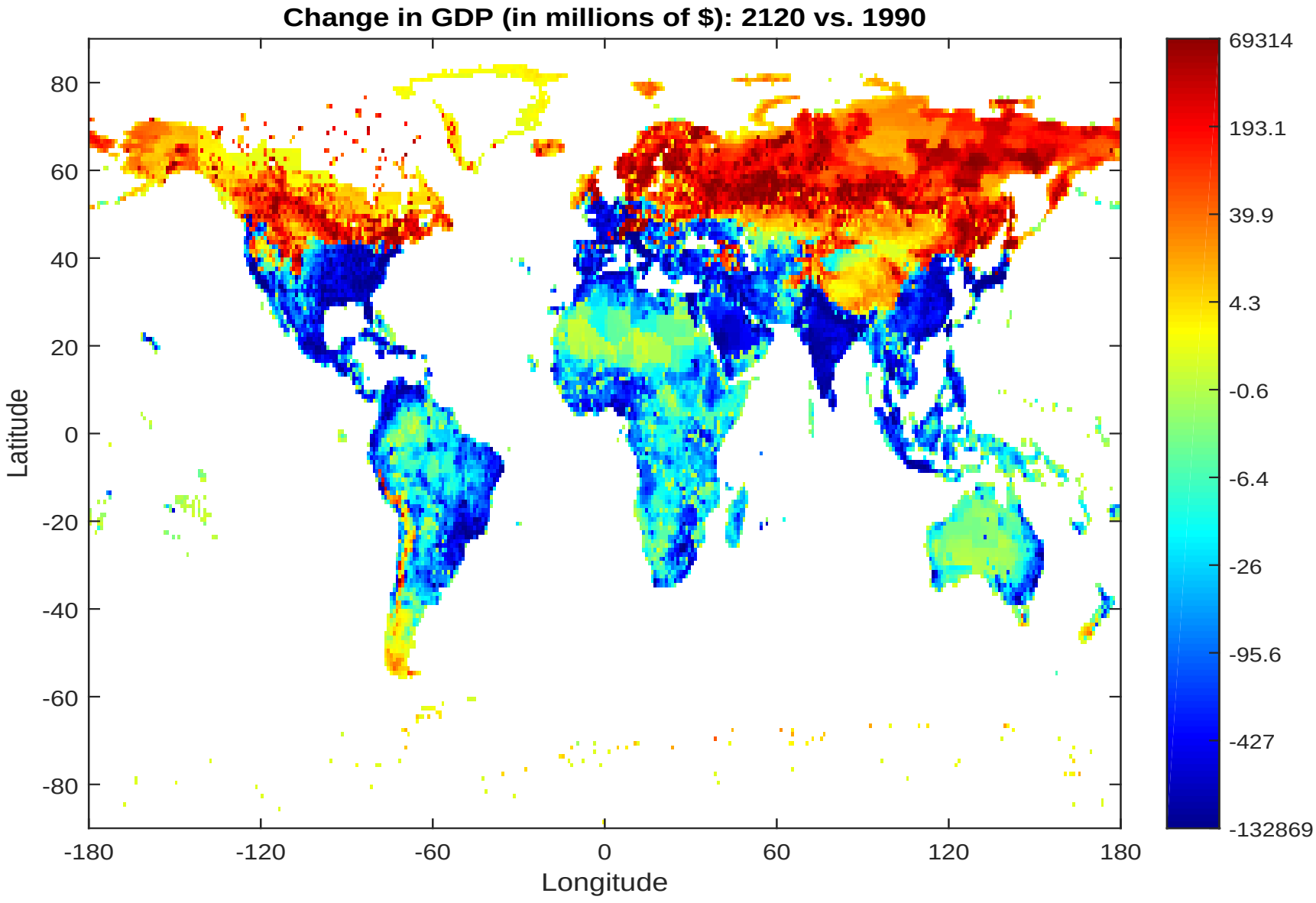

Change in GDP (in millions of $): 2070 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

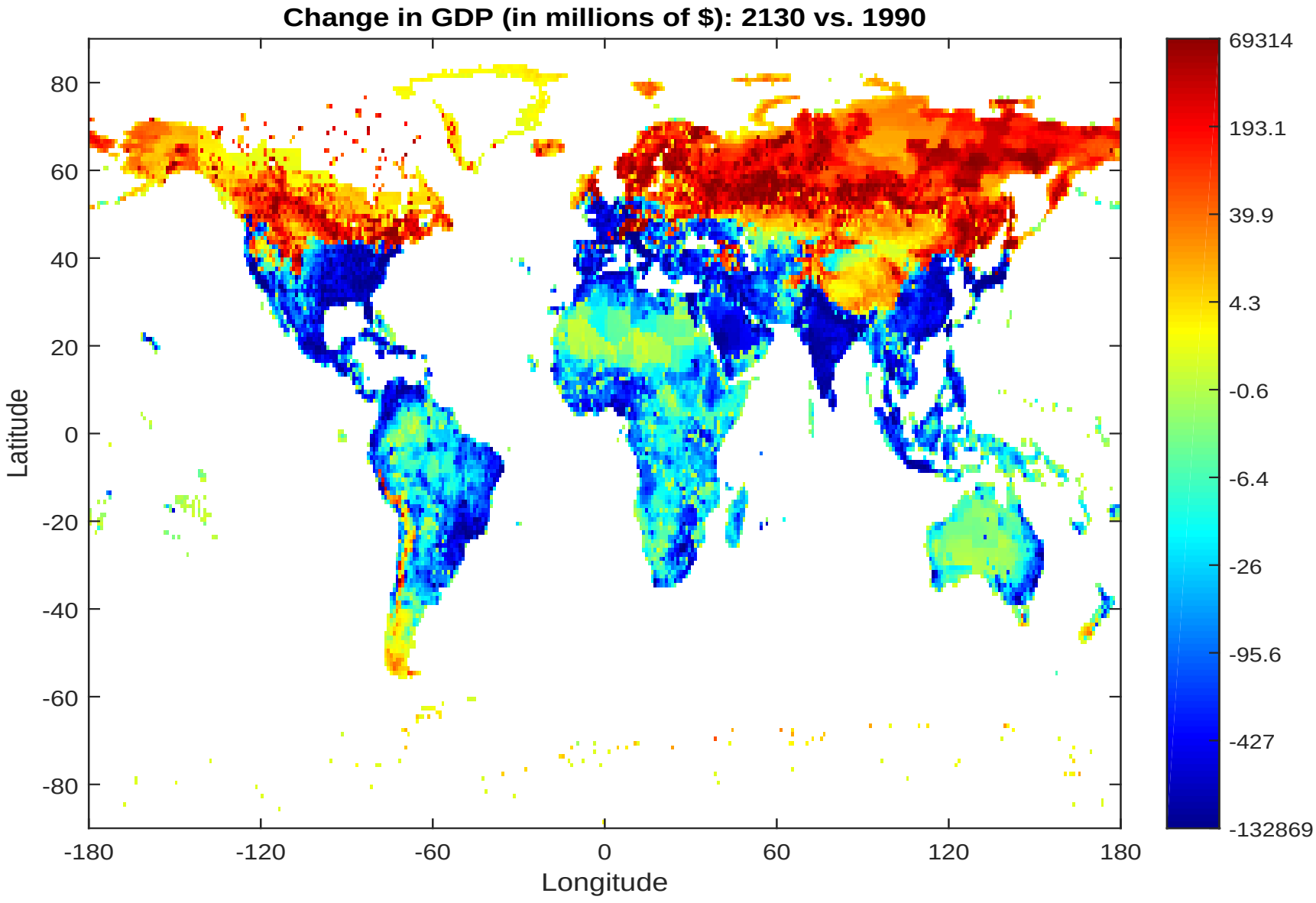

Change in GDP (in millions of $): 2080 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

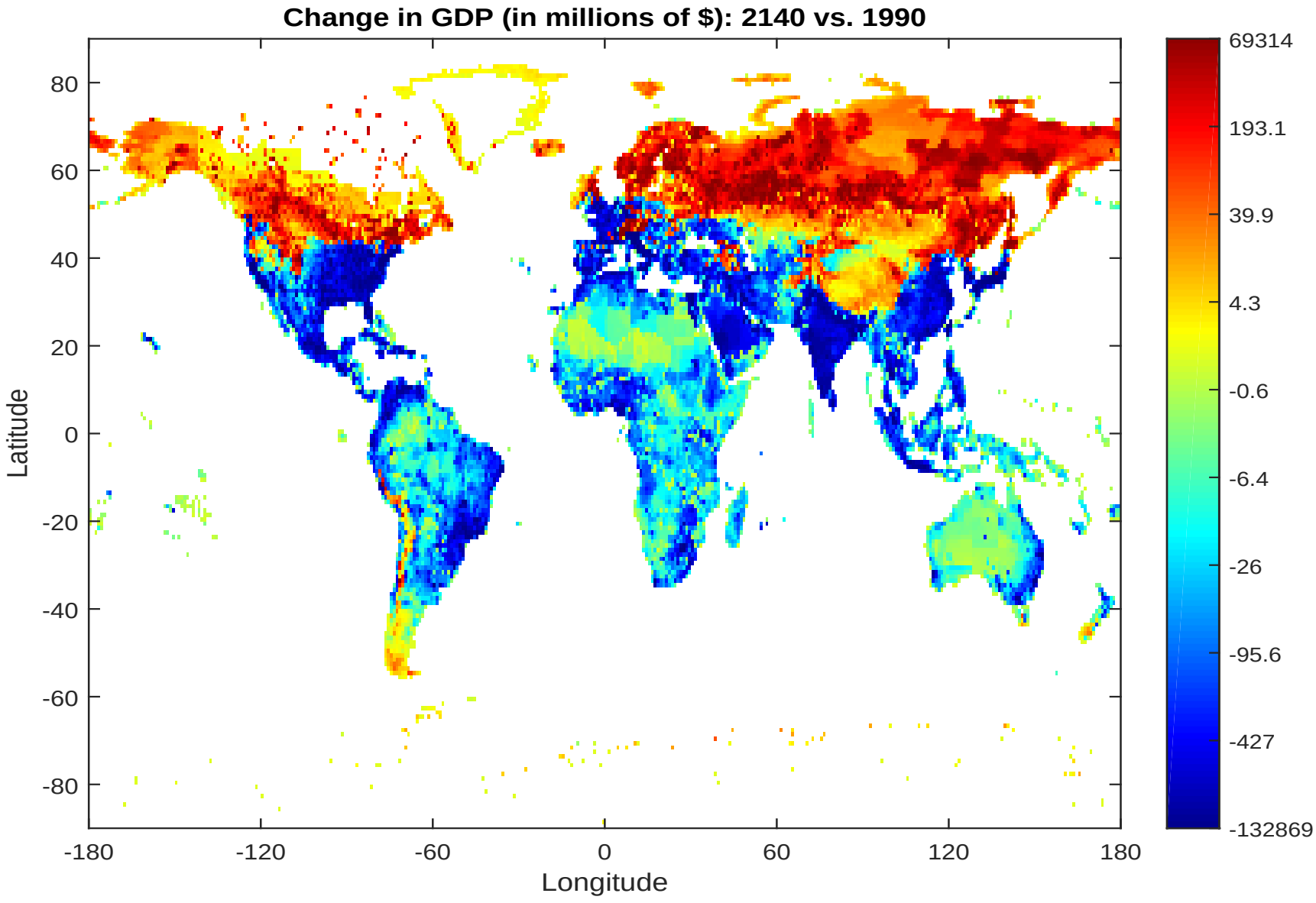

Change in GDP (in millions of $): 2090 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

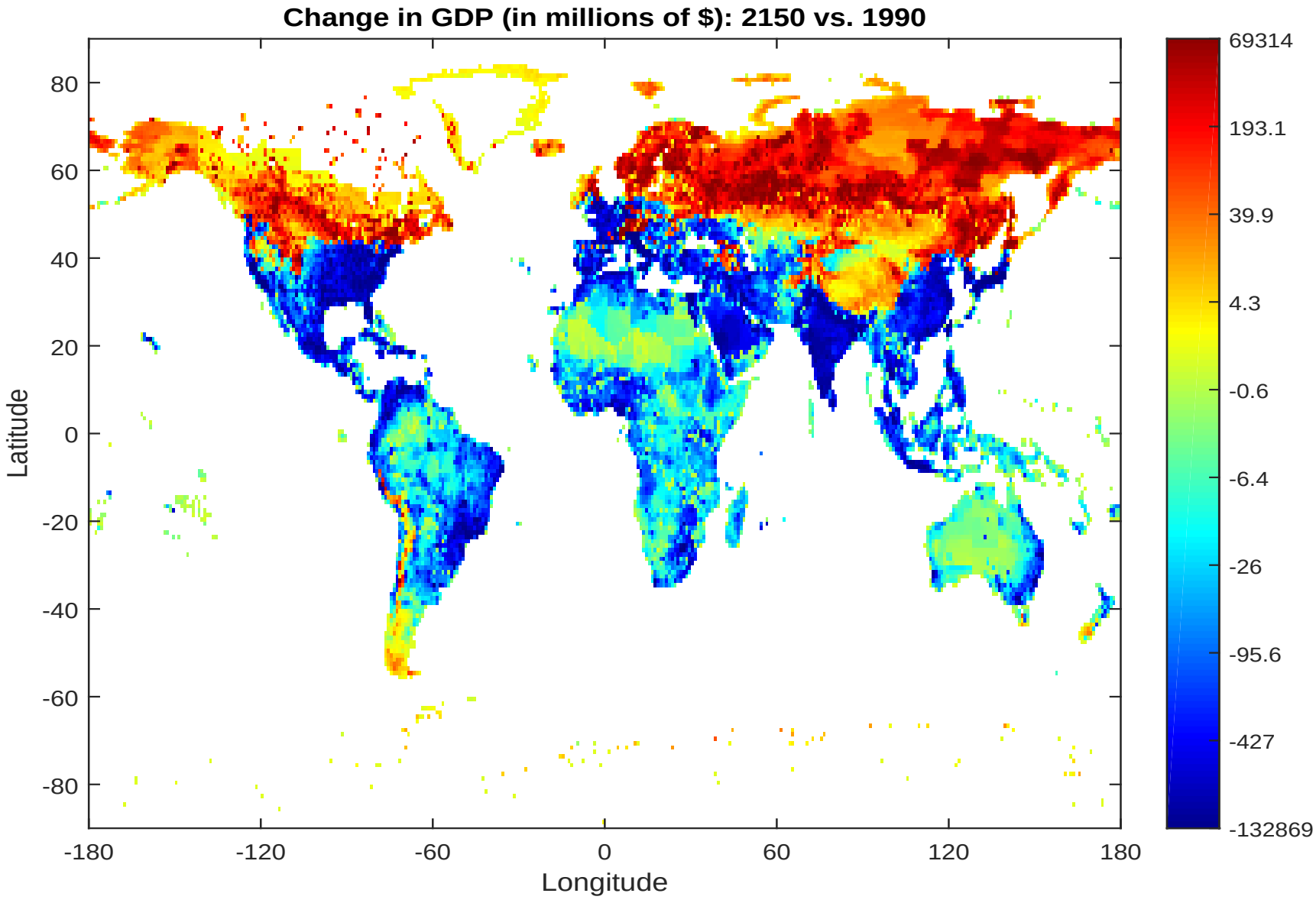

Change in GDP (in millions of $): 2100 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

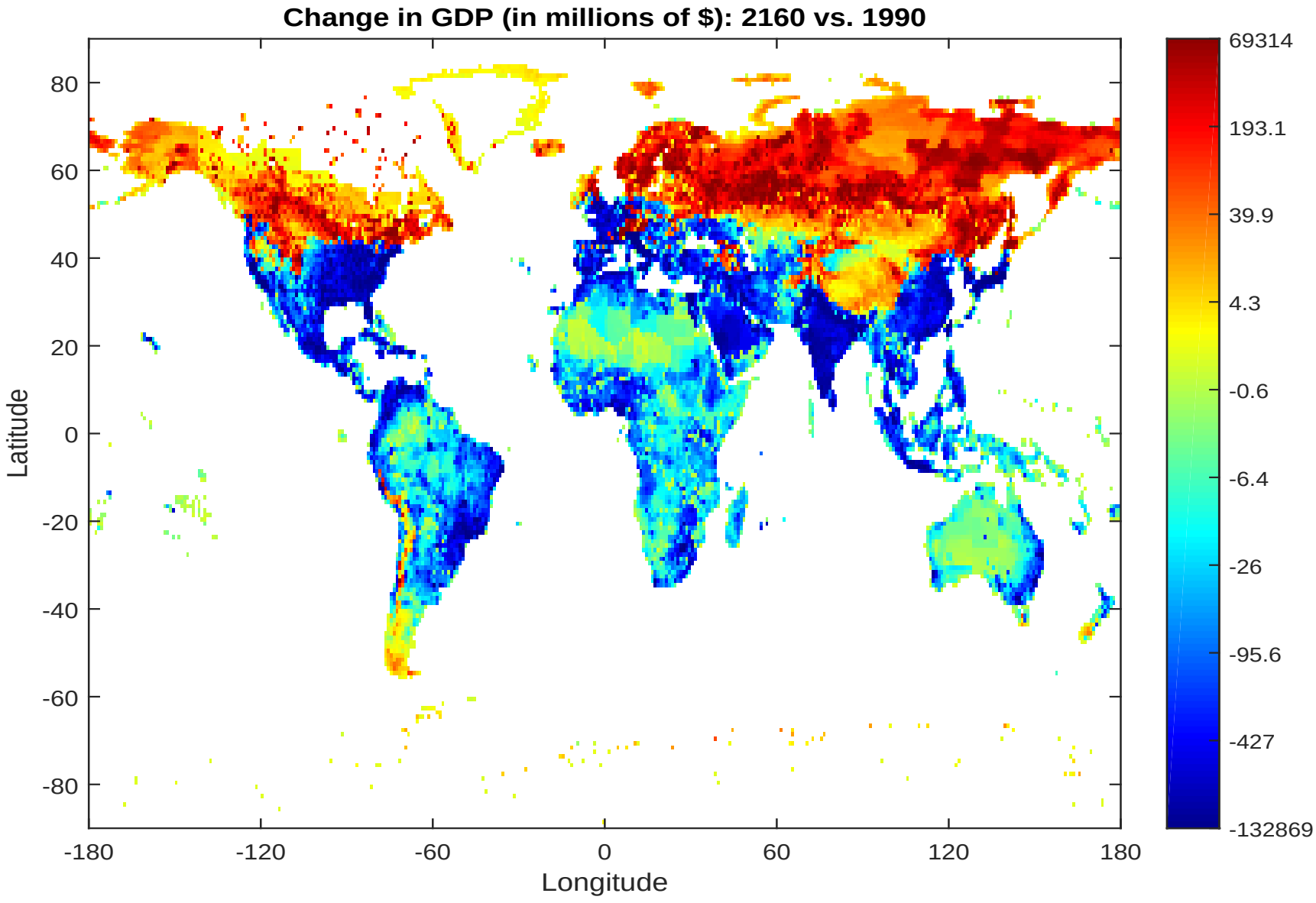

Change in GDP (in millions of $): 2110 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

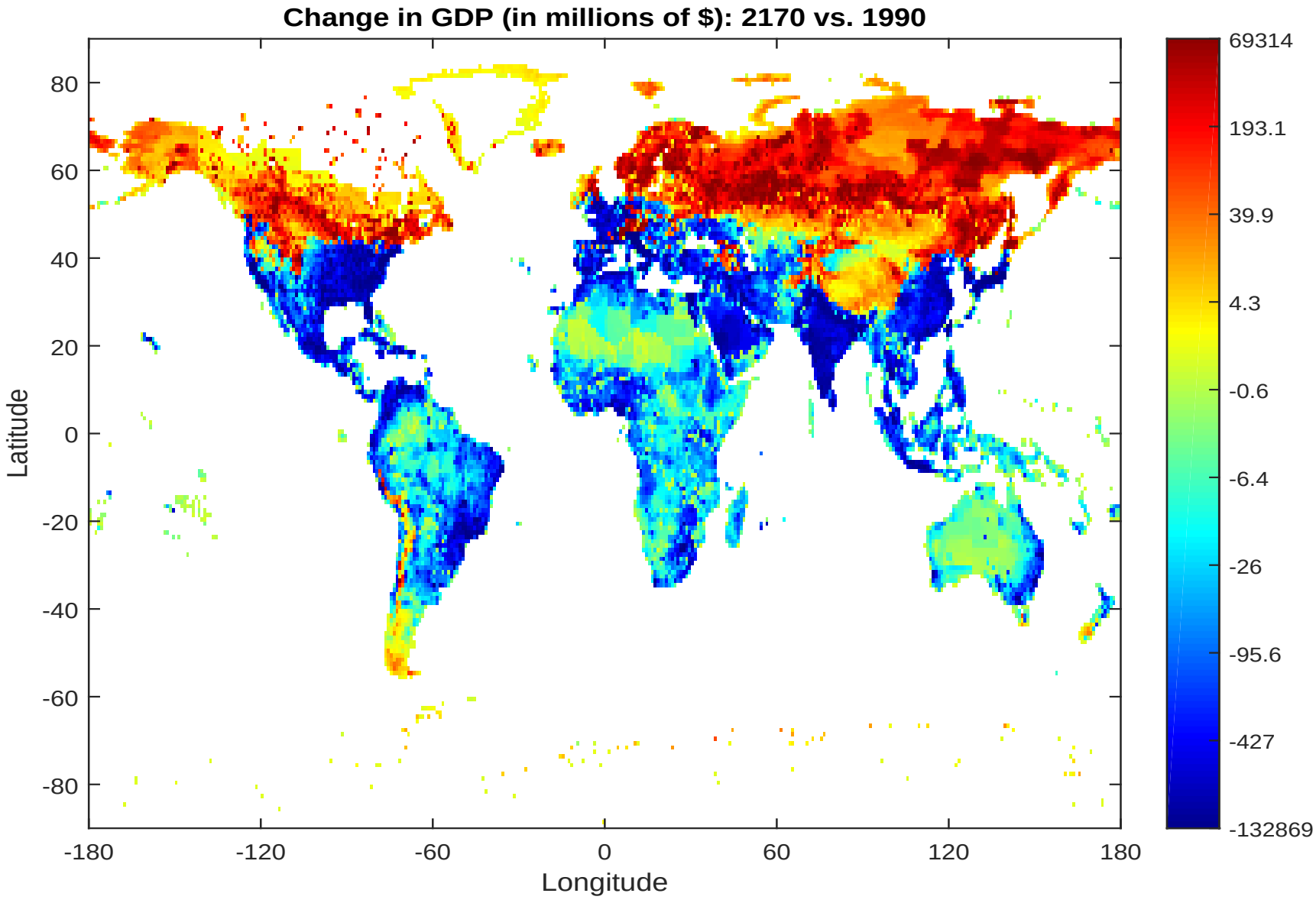

Change in GDP (in millions of $): 2120 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

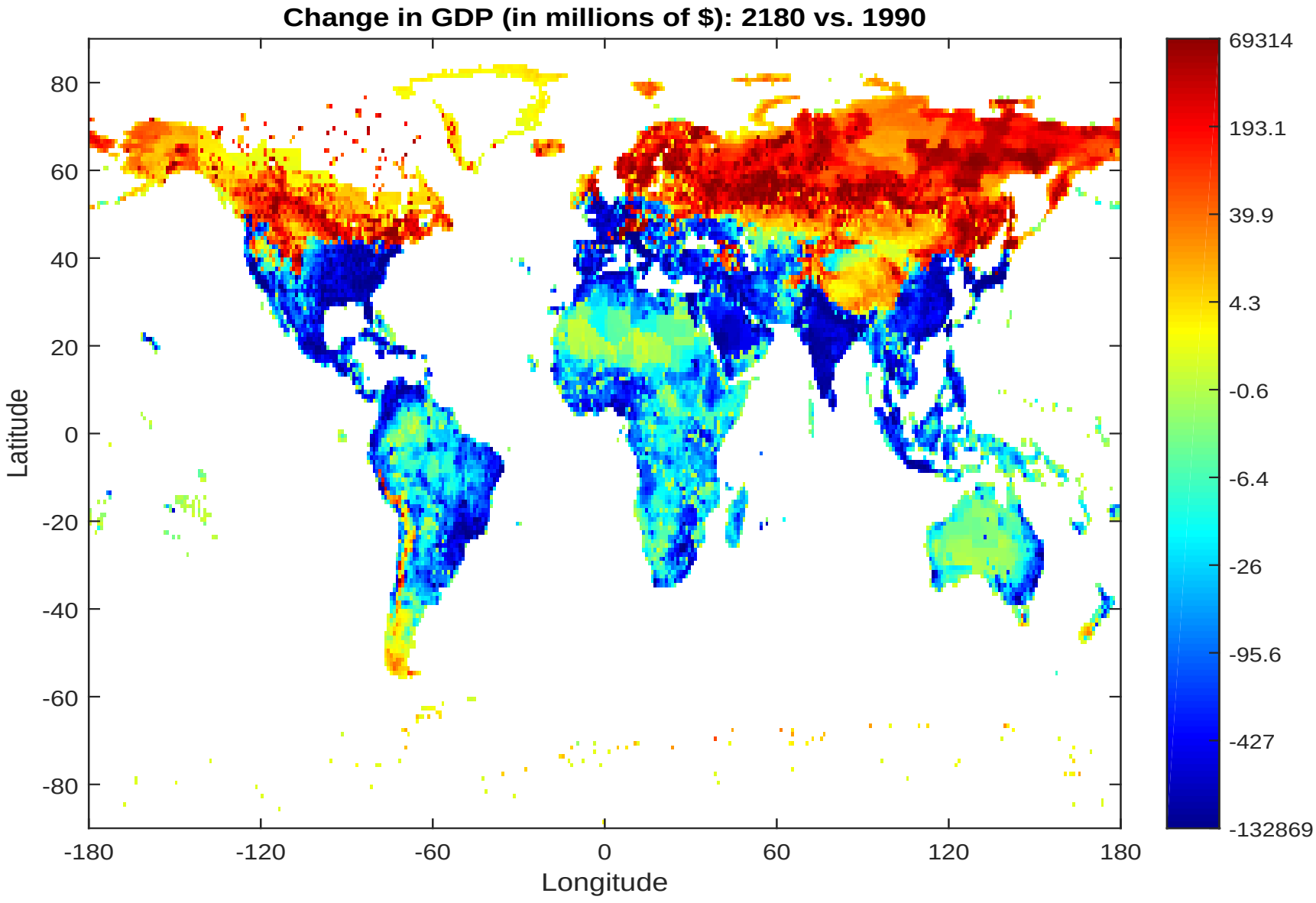

Change in GDP (in millions of $): 2130 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

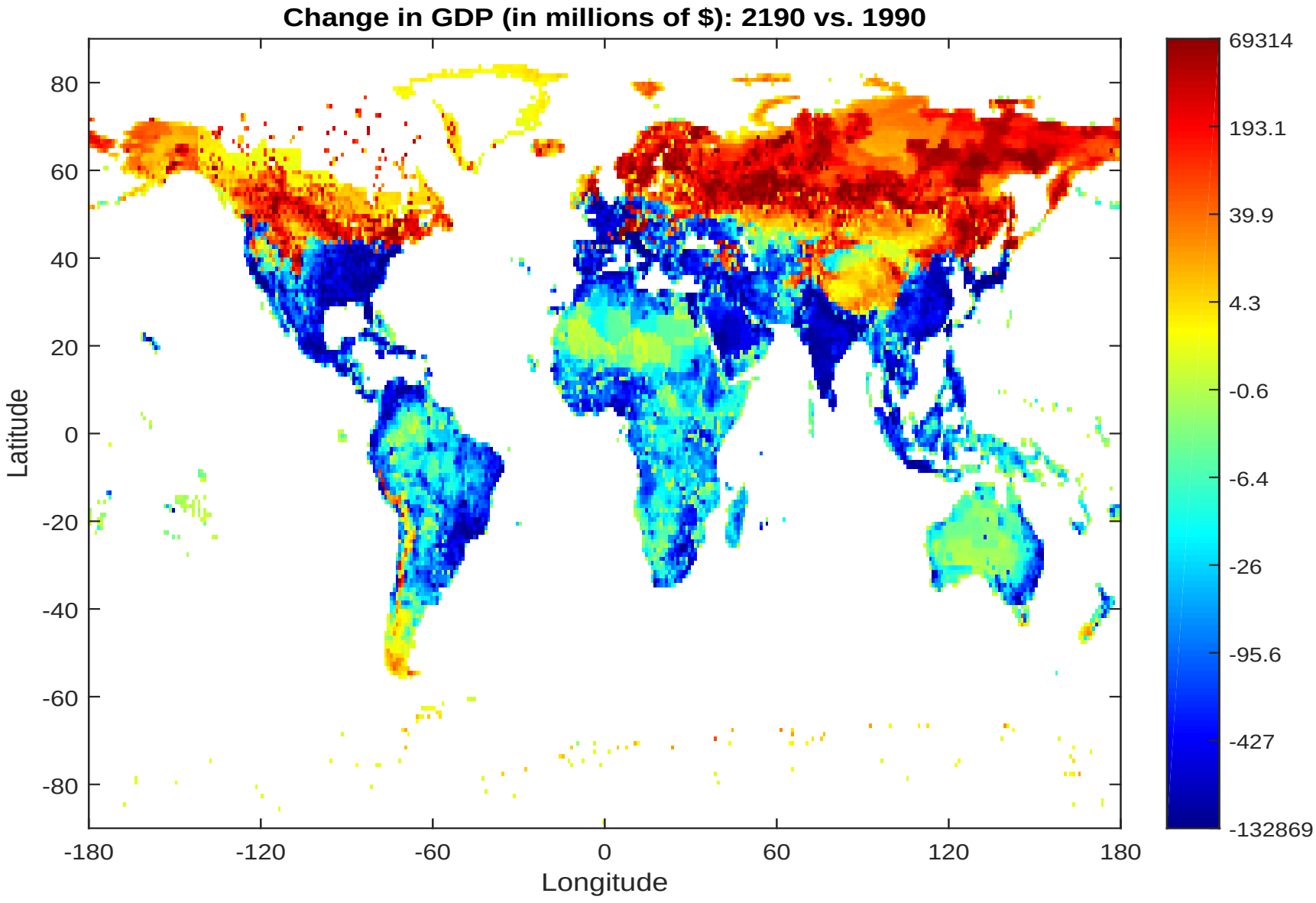

Change in GDP (in millions of $): 2140 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869

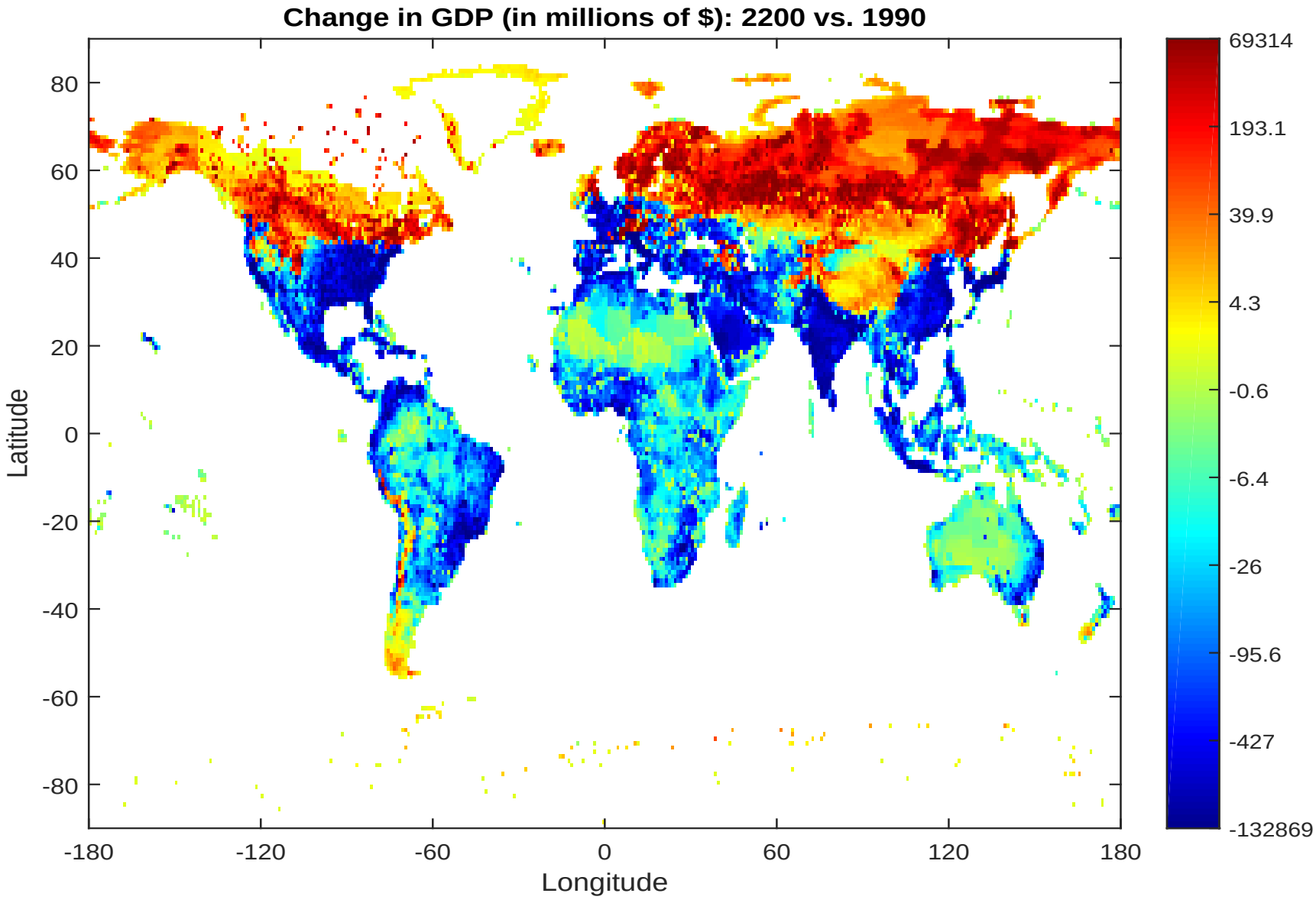

Change in GDP (in millions of $): 2150 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869


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

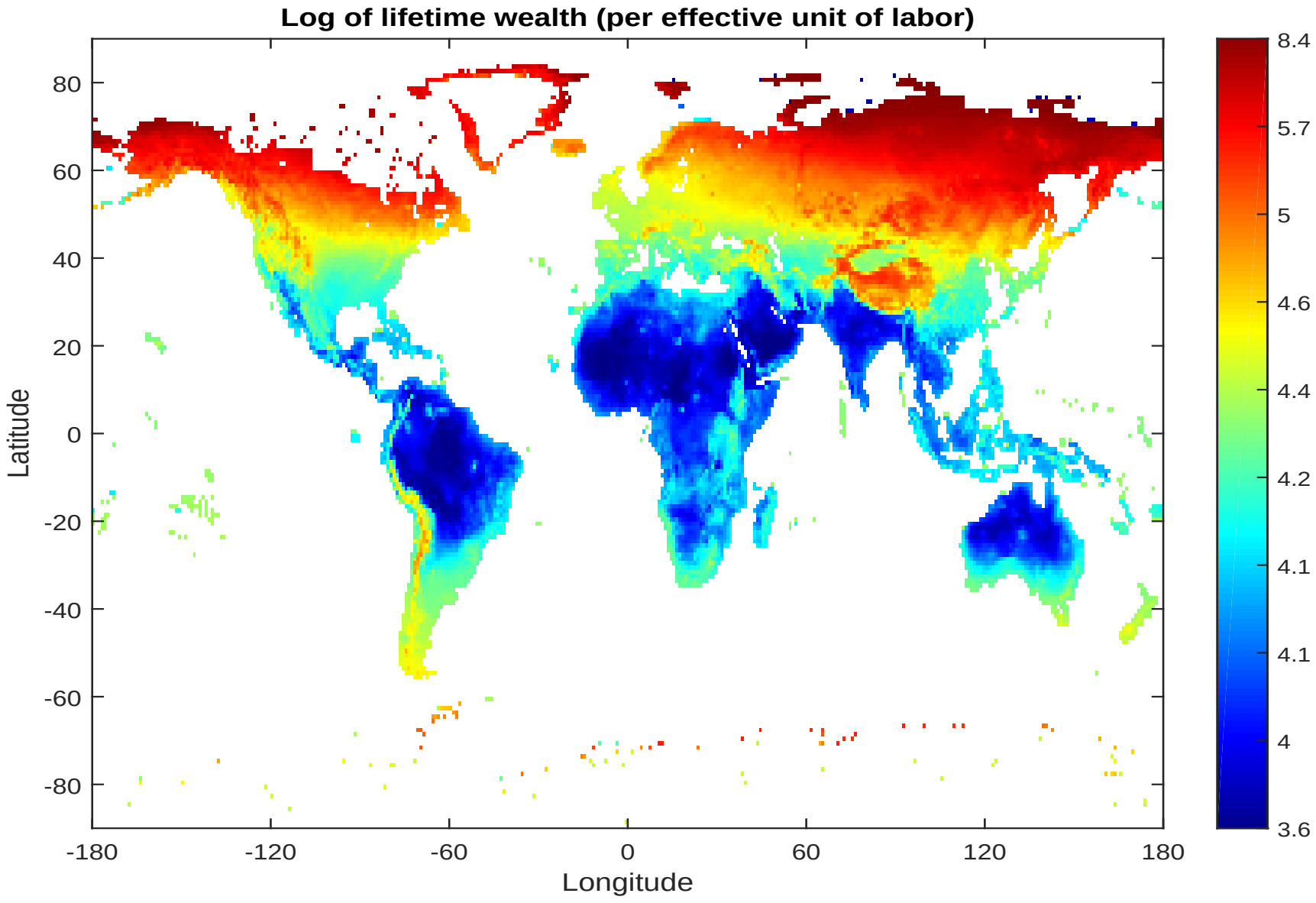

Change in GDP (in millions of $): 2170 vs. 1990
Latitude
Longitude
80
60
40
20
0
-20
-40
-60
-80
-180
-120
-60
0
60
120
180
69314
193.1
39.9
4.3
-0.6
-6.4
-26
-95.6
-427
-132869


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

picture: migration pressures (wealth effects of climate change)


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

Conclusions

Take-away:

- Results from our model: climate change is about relative effects much more than about average effects!
- Hugely heterogeneous effects despite use of Nordhaus's (commonly criticized) modest global damage function.
- In particular, huge disagreements about taxes (so huge transfer payments needed to compensate those losing from carbon tax).
- Strong migration pressures.

Future: a million things.