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Forecasting the 2020 and 2030 demand for radioactive materials used in medicine

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Outline

- Backgroud
- Variables
- Methods
- Results
- Conclusion

Background/Objective

- As the population of the world increases and as people around the world live longer lives, the need to treat aging-associated diseases increases.
- Some of these treatments and other medical research use radiological materials such as Cobalt-60, Iridium-192, and Cesium-137.
- These materials could be used to fabricate a radiological dispersion device or "dirty bomb".

Objective: To forecast, by country, the future demand of medical equipments that use Cobalt-60 and Iridium-192.

Variables

- Dependent variable [Data available for 2011 only.]
  - Co60: Number of equipments, in a country, that use Cobalt-60.
  - HDR(High Dose Rate): Number of equipments, in a country, that use an HDR-Co60 or HDR-Ir192.
- Independent variables

1. HDI:Human Development Index. [Data available through 2011.]
2. GDP: Gross Domestic Product (per capita).
3. CR: The number of deaths caused by cancer.
4. CPI: Corruption Perceptions Index [0 means highly corrupted].
5. CO2: Carbon dioxide emissions.
6. CRUPT: Control of corruption [Z=-2.5 means weak government control].
7. Total population: In thousands. [Data available through 2030.]
8. Hemisphere: Indicator (southern vs. northern).
9. Region: South America, Africa, Asia and Oceania, Eastern Europe, Small Islands, North America and Western Europe, Middle East.
10. Country Age: Independence or Birthday for Country [2051 minus the Calendar years (negative value for BC years) in 2011].

Statistical methods

- To model Co60 and HDR for the year 2011(extrapolation for the years 2020 and 2030) we use Quasi-Poisson GLM:

$$\begin{cases} Y_i = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \epsilon_i, \;\; Var(Y) = \phi E(Y) \\ Y_i \sim Poisson(\mu_i) \\ log(\mu_i) = E(Y|X) = \beta_0 + \sum_{i=1}^{k} \beta_i X_i \end{cases}$$

- To forecast the values of HDI, GDP, CR, CPI, CO2 and CRUPT for the years 2020 and 2030, we use:
  - Local polynomial regression fitting (loess) [imputation]
  - Time series with regressors
  - Non-linear regression
  - Linear regression

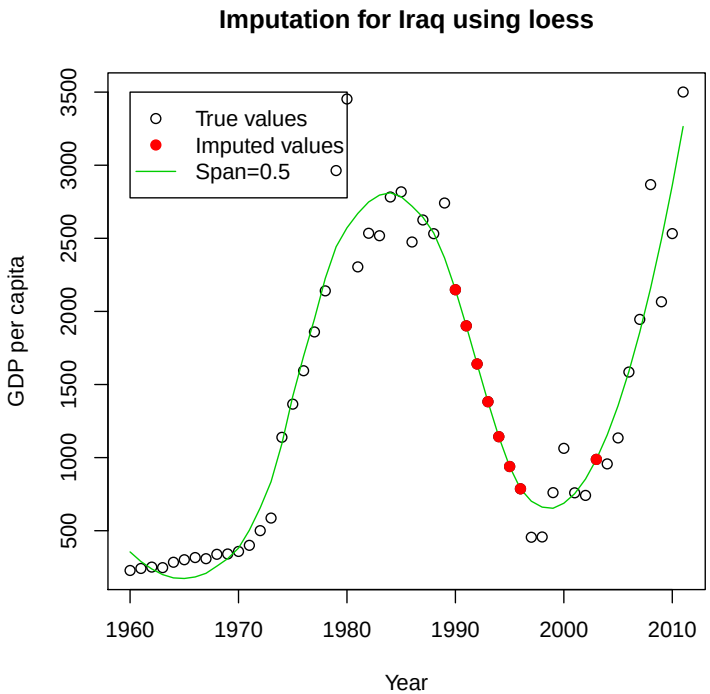

Figure 1: GDP (per capita) over time for Iraq. Solid dots are the imputed values using loess with span=0.5.

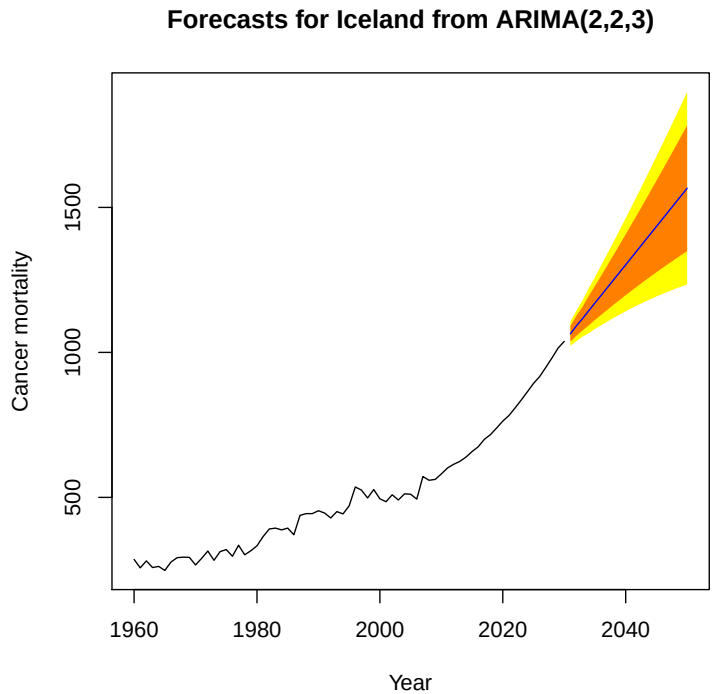

Figure 2: ARIMA Modeling for CR (total death due to cancer) for Iceland with Total Population as a regressor. Note that before forecasting, we used loess to impute the missing values.

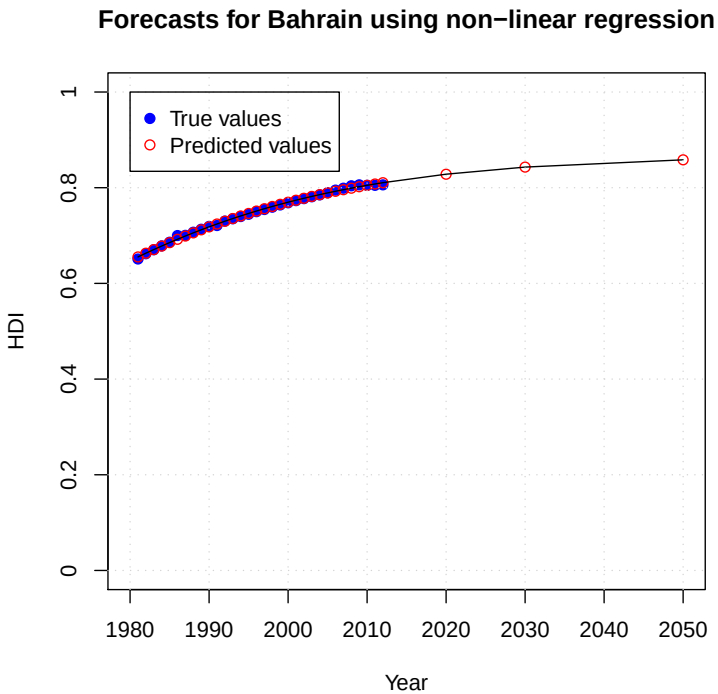

Figure 3: HDI vs. time in a Nonlinear Regression Growth Like Curve for Bahrain. Solid points in blue are the actual values and the non-solid red points are predicted ones.

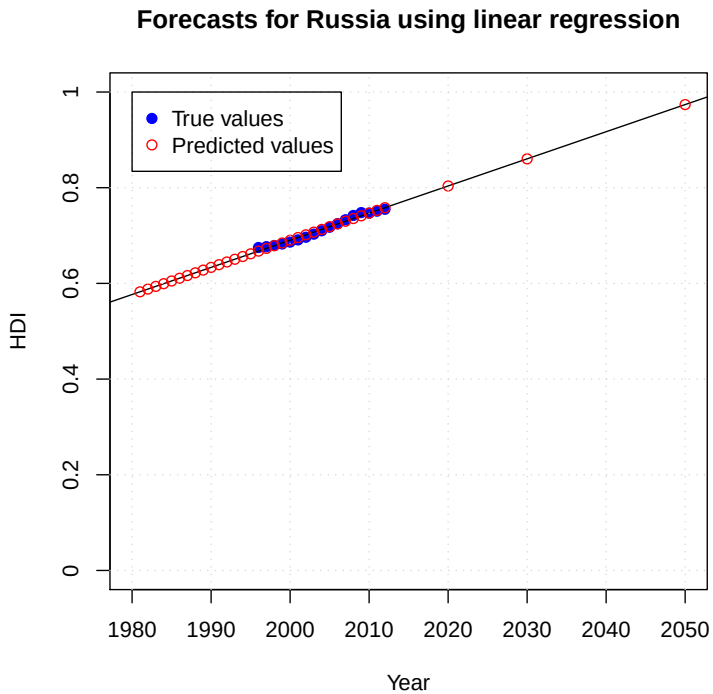

Figure 4: HDI vs. Time in a Simple Linear Regression for Russia. Solid points in blue are the actual values and the non-solid red points are predicted ones.

Results (Modeling Co60)

```
glm(formula = Co60 ~ CO2 + CPI + CRUPT + factor(H.Type) + factor(region) +
    log(age) + logCR + popTotal + CPI:factor(region), family = quasipoisson(link = "log"),
    data = final)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-5.2144  -1.1638  -0.5566   0.6294   6.3783

Coefficients:
                          Estimate Std. Error t value Pr(>|t|)
(Intercept)             -4.234e+00  7.790e-01  -5.435 2.30e-07 ***
CO2                      6.287e-02  1.483e-02   4.241 3.98e-05 ***
CPI                     -3.222e-01  2.120e-01  -1.520 0.130706
CRUPT                    6.730e-01  3.644e-01   1.847 0.066791 .
factor(H.Type)S         -6.577e-01  1.846e-01  -3.563 0.000499 ***
factor(region)2         -3.963e+00  1.080e+00  -3.668 0.000344 ***
factor(region)3         -5.843e-01  4.718e-01  -1.238 0.217611
factor(region)4          8.162e-01  5.283e-01   1.545 0.124538
factor(region)5         -3.604e+00  2.944e+00  -1.224 0.222886
factor(region)6         -1.180e+00  6.745e-01  -1.750 0.082332 .
factor(region)7          3.557e-01  7.133e-01   0.499 0.618765
log(age)                -1.150e-01  5.283e-02  -2.177 0.031125 *
logCR                    8.761e-01  5.427e-02  16.142  < 2e-16 ***
popTotal                 7.073e-07  1.873e-07   3.777 0.000232 ***
CPI:factor(region)2      7.274e-01  3.095e-01   2.350 0.020120 *
CPI:factor(region)3     -1.199e-01  1.217e-01  -0.985 0.326413
CPI:factor(region)4     -4.204e-01  1.469e-01  -2.863 0.004831 **
CPI:factor(region)5      4.475e-01  5.747e-01   0.779 0.437502
CPI:factor(region)6     -9.635e-02  1.345e-01  -0.716 0.474921
CPI:factor(region)7     -3.360e-01  2.239e-01  -1.501 0.135630
---
Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for quasipoisson family taken to be 3.152458)
```

Figure 5: Co60 Model: Best Model Based on AIC, Max=613(China), R^2=0.977795.

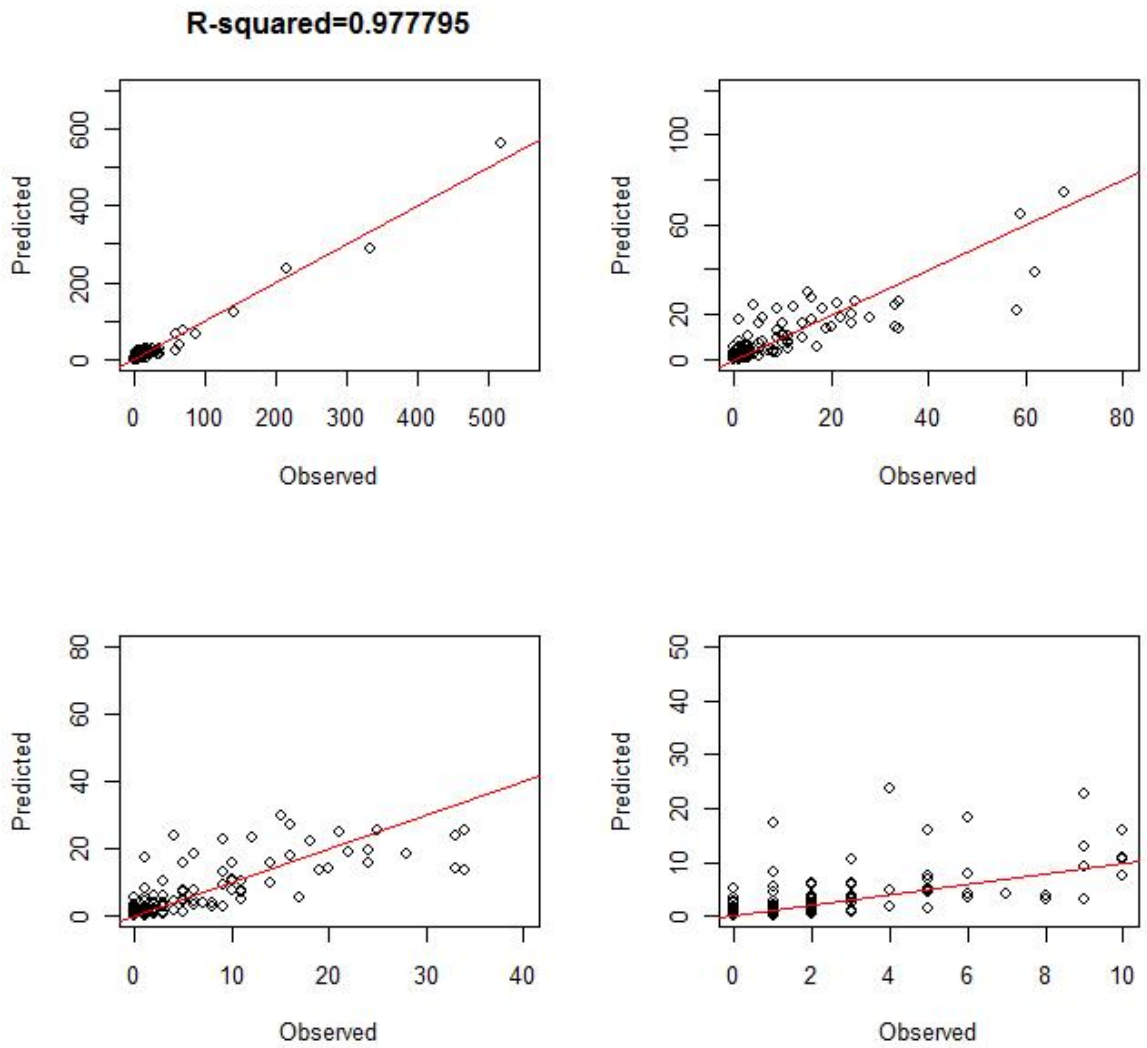

Figure 6: The association between the observed and predicted values of Co60.

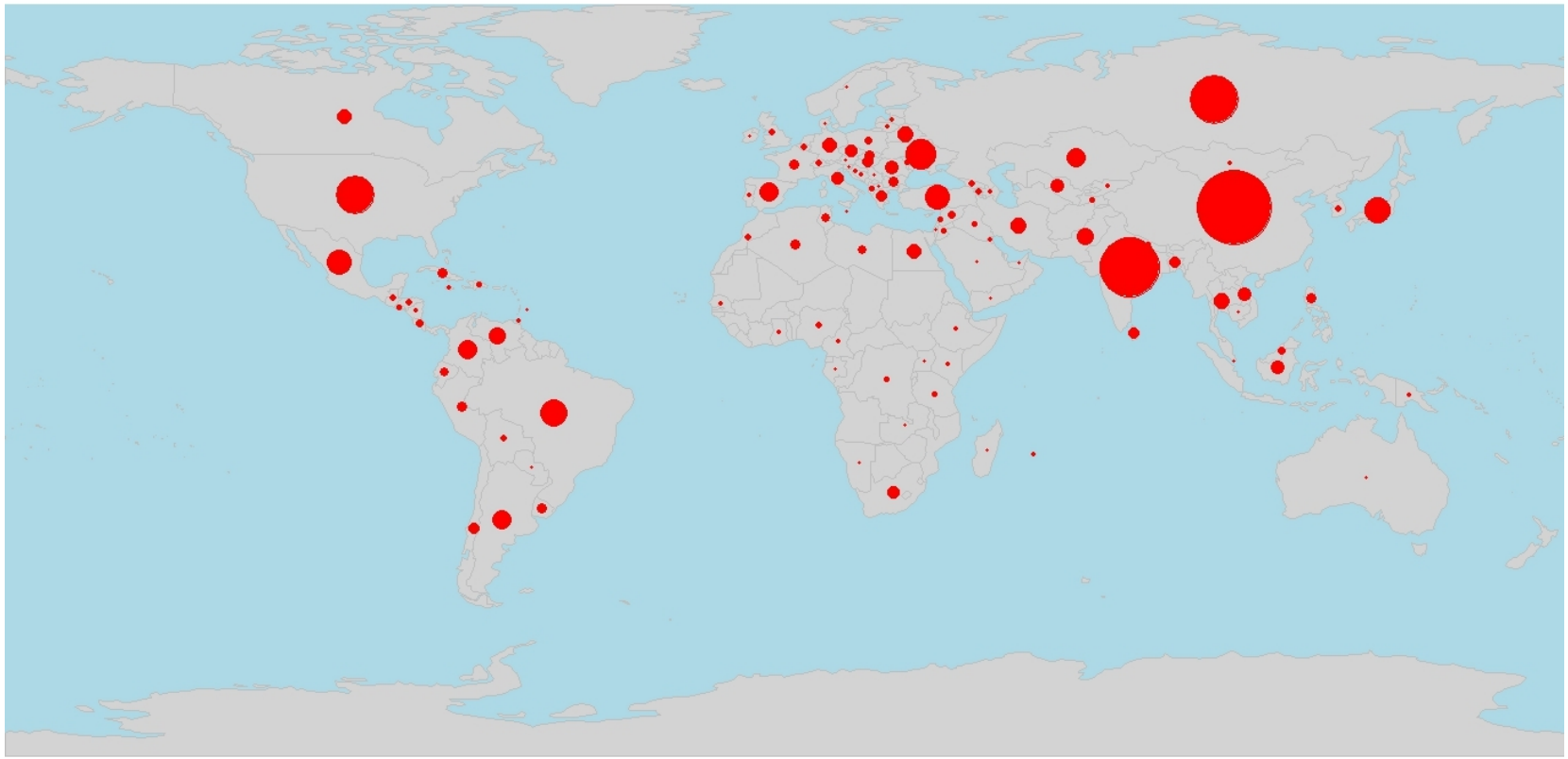

Figure 7: True Co60 in 2011

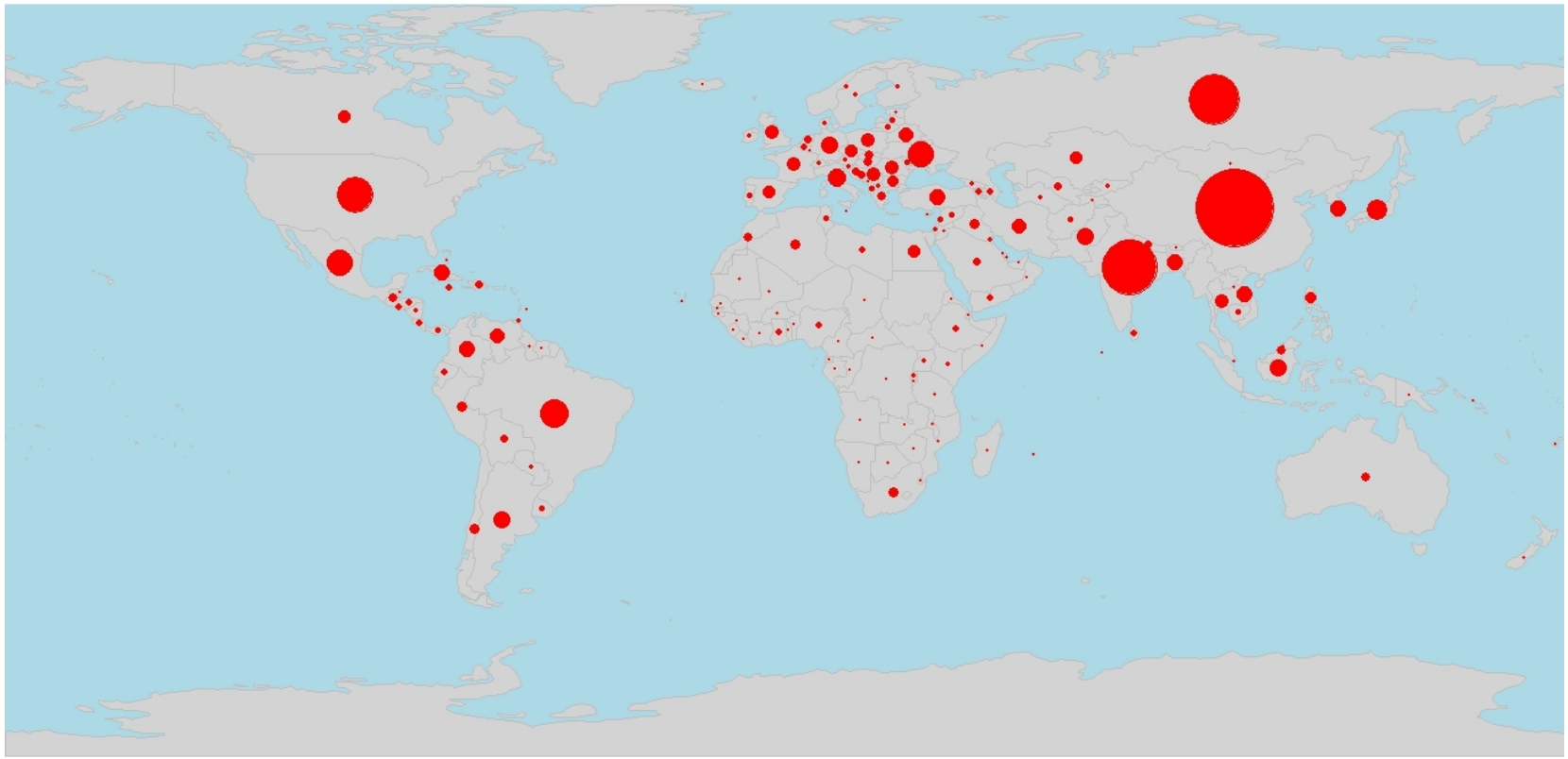

Figure 8: Predictied Co60 in 2011

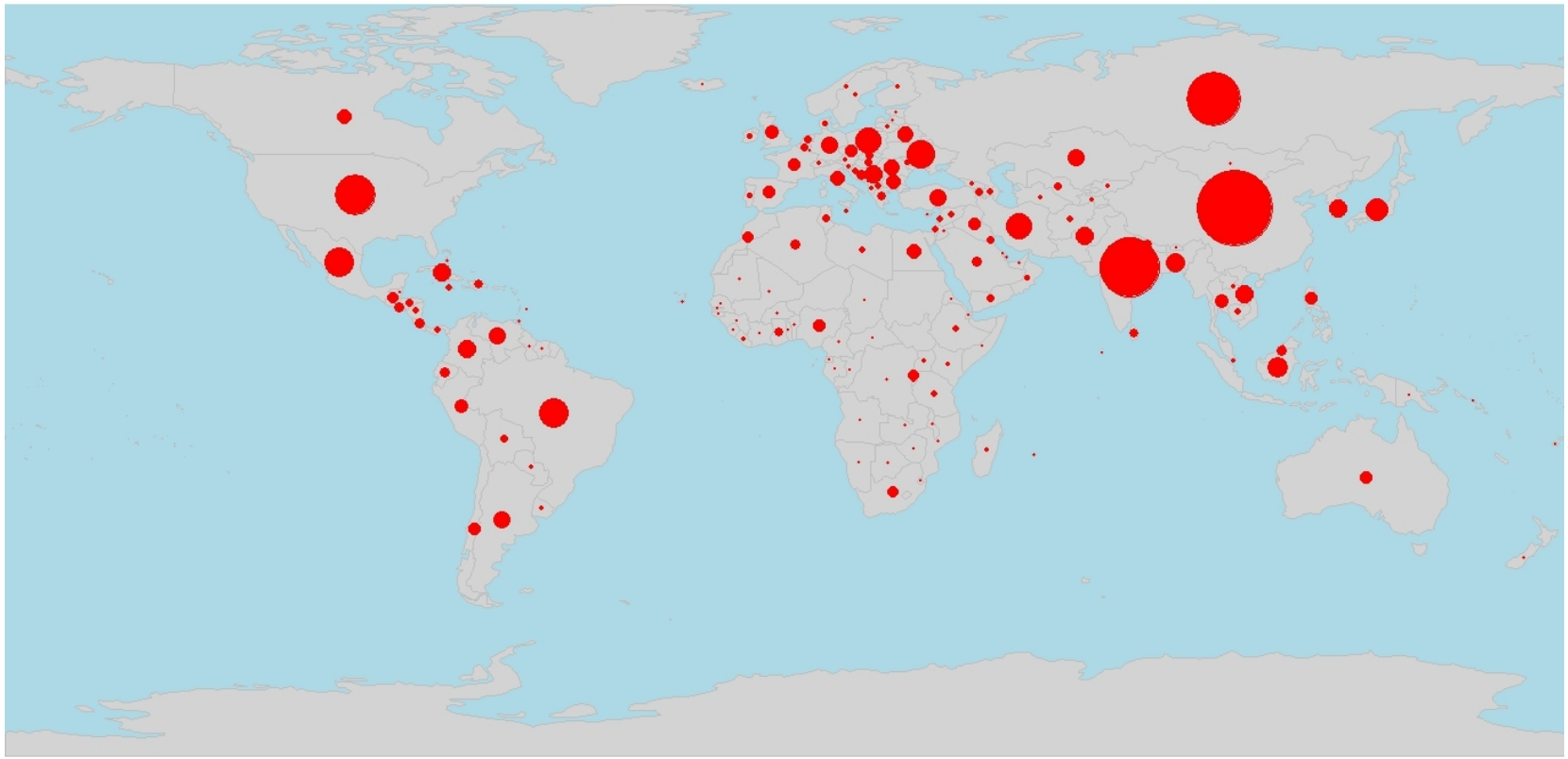

Figure 9: Predicted Co60 in 2020

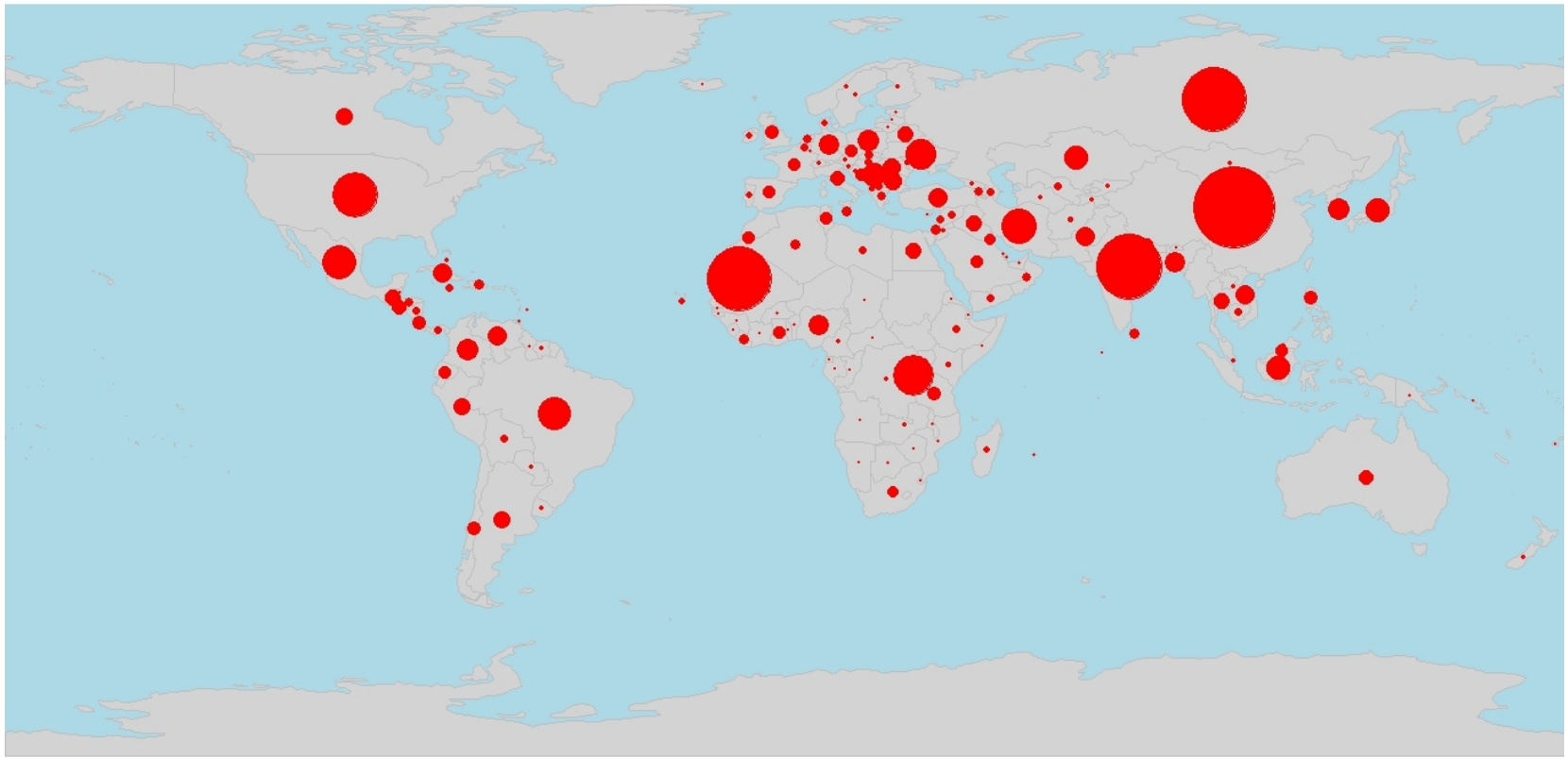

Figure 10: Predicted Co60 in 2030

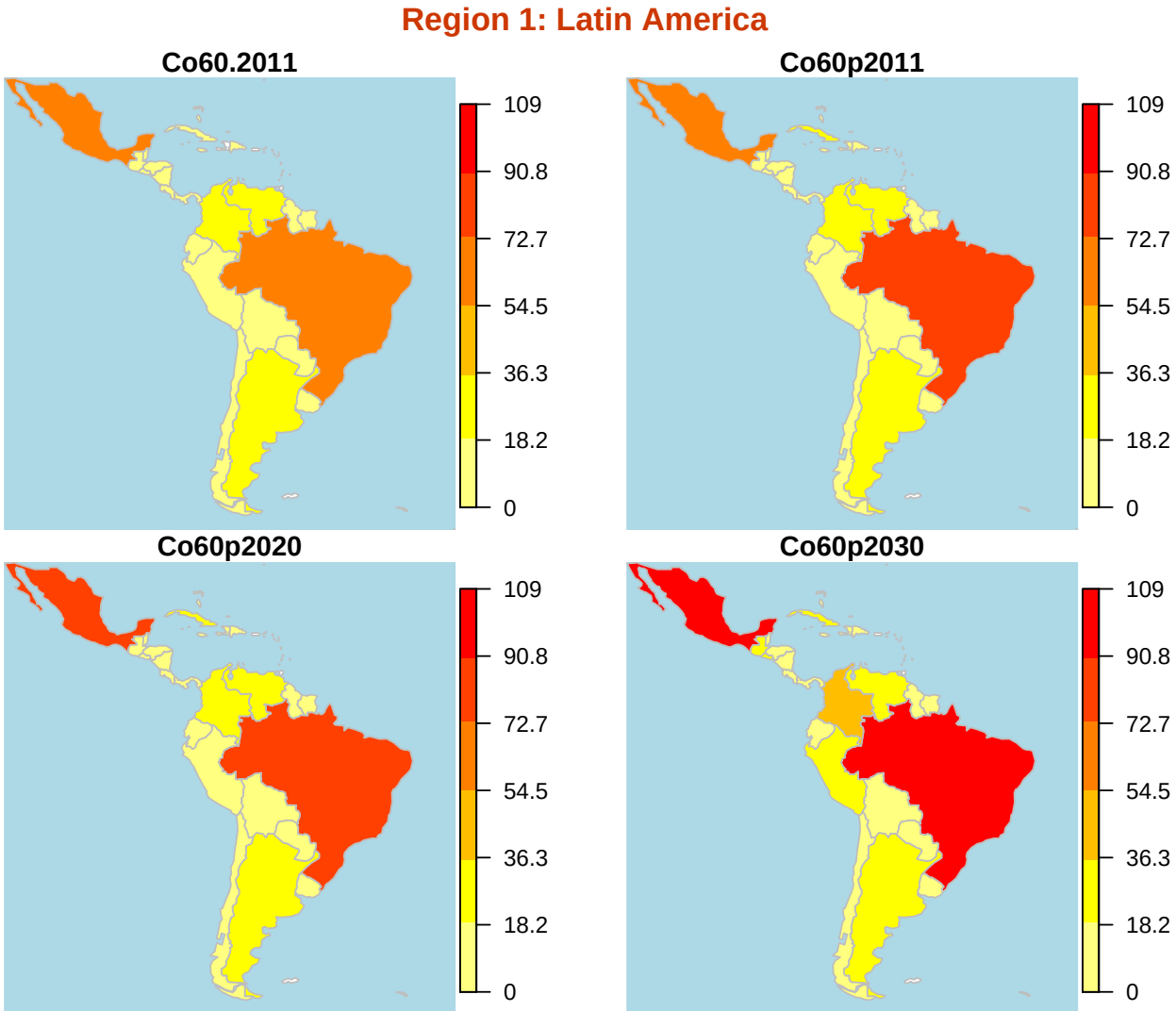

Figure 11: Latin America all

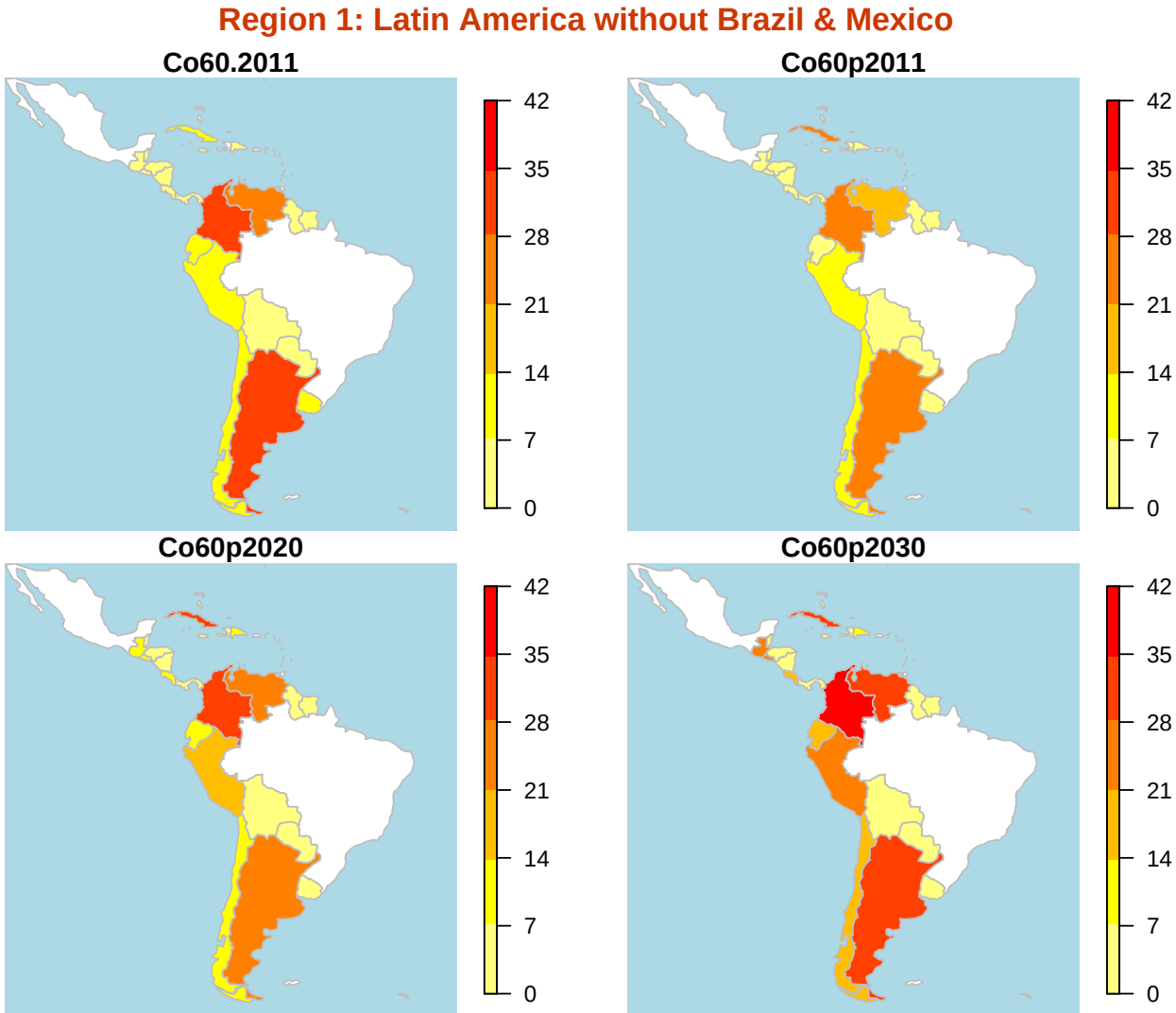

Figure 12: Latin America without Brazil and Mexico

Region 2: Africa

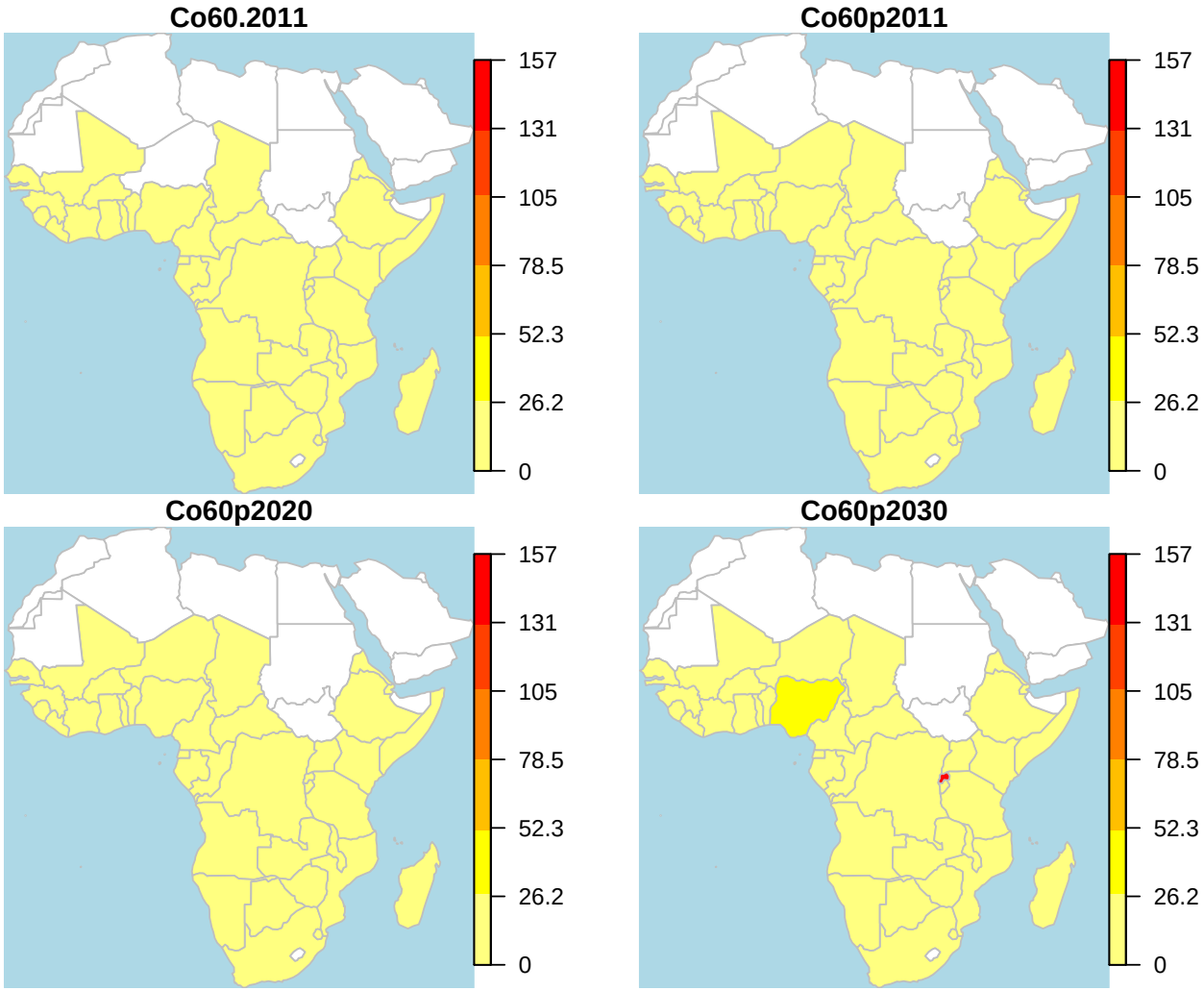

Figure 13: Africa all

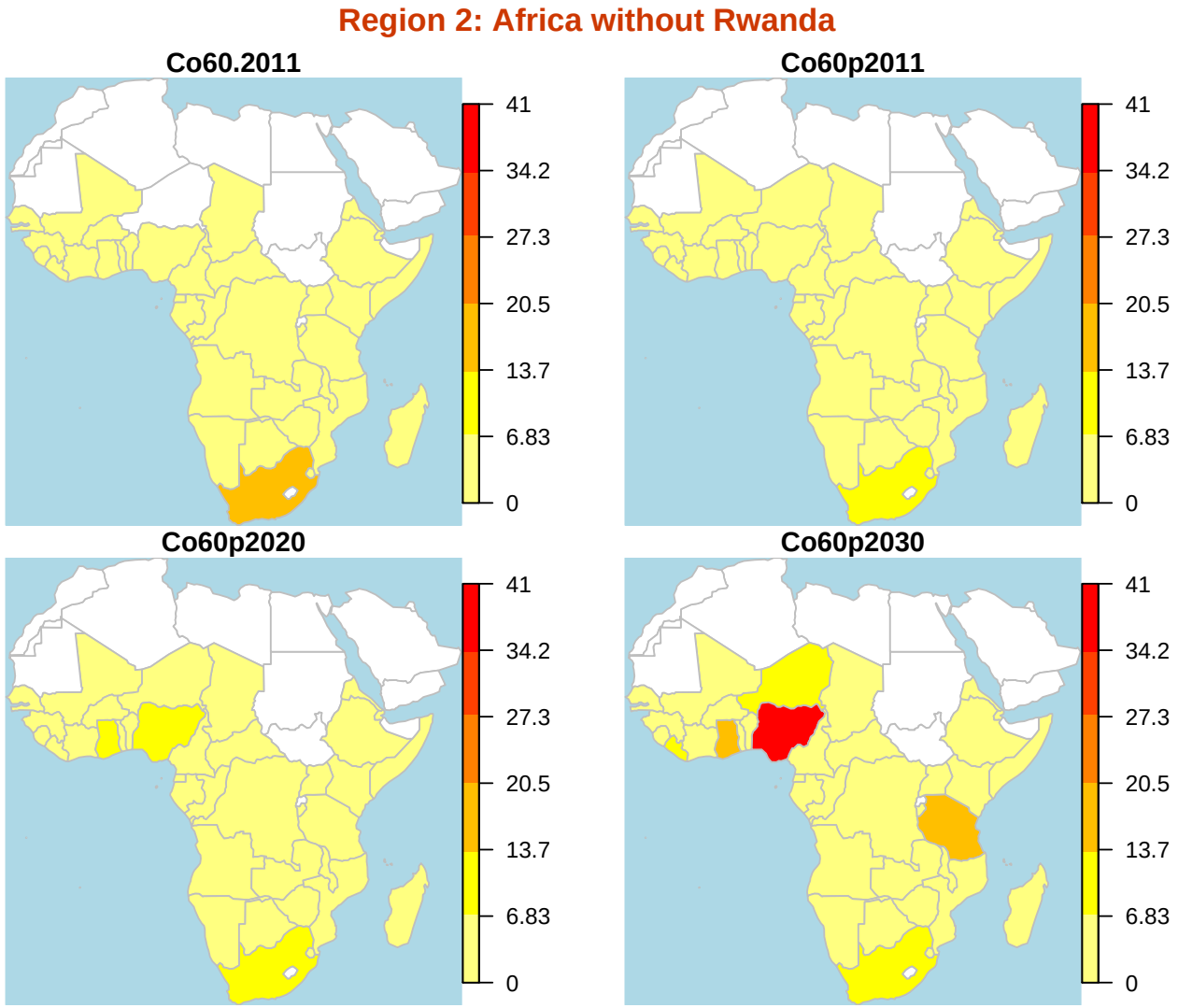

Figure 14: Africa without Rwanda

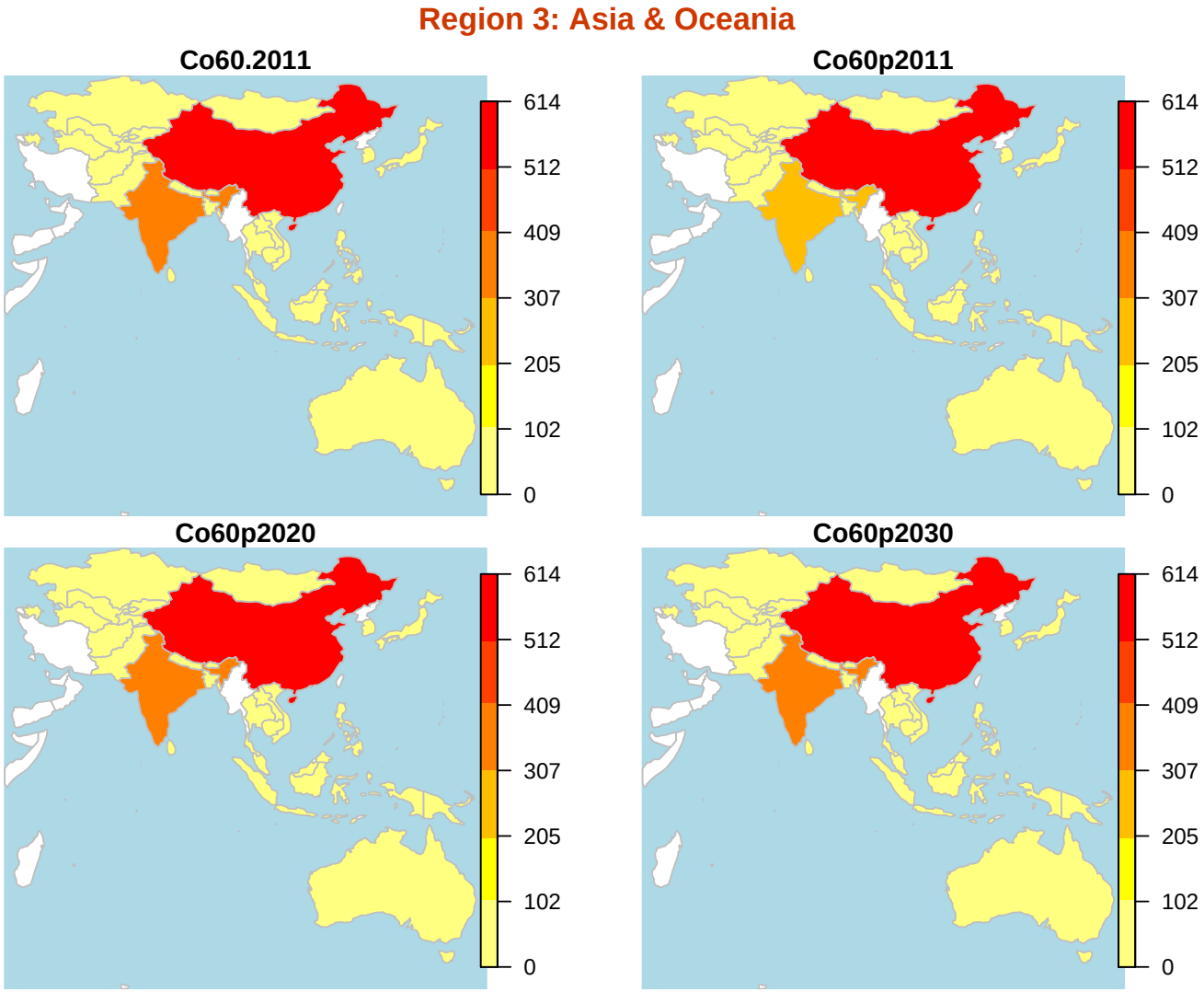

Figure 15: Asia and Oceania all

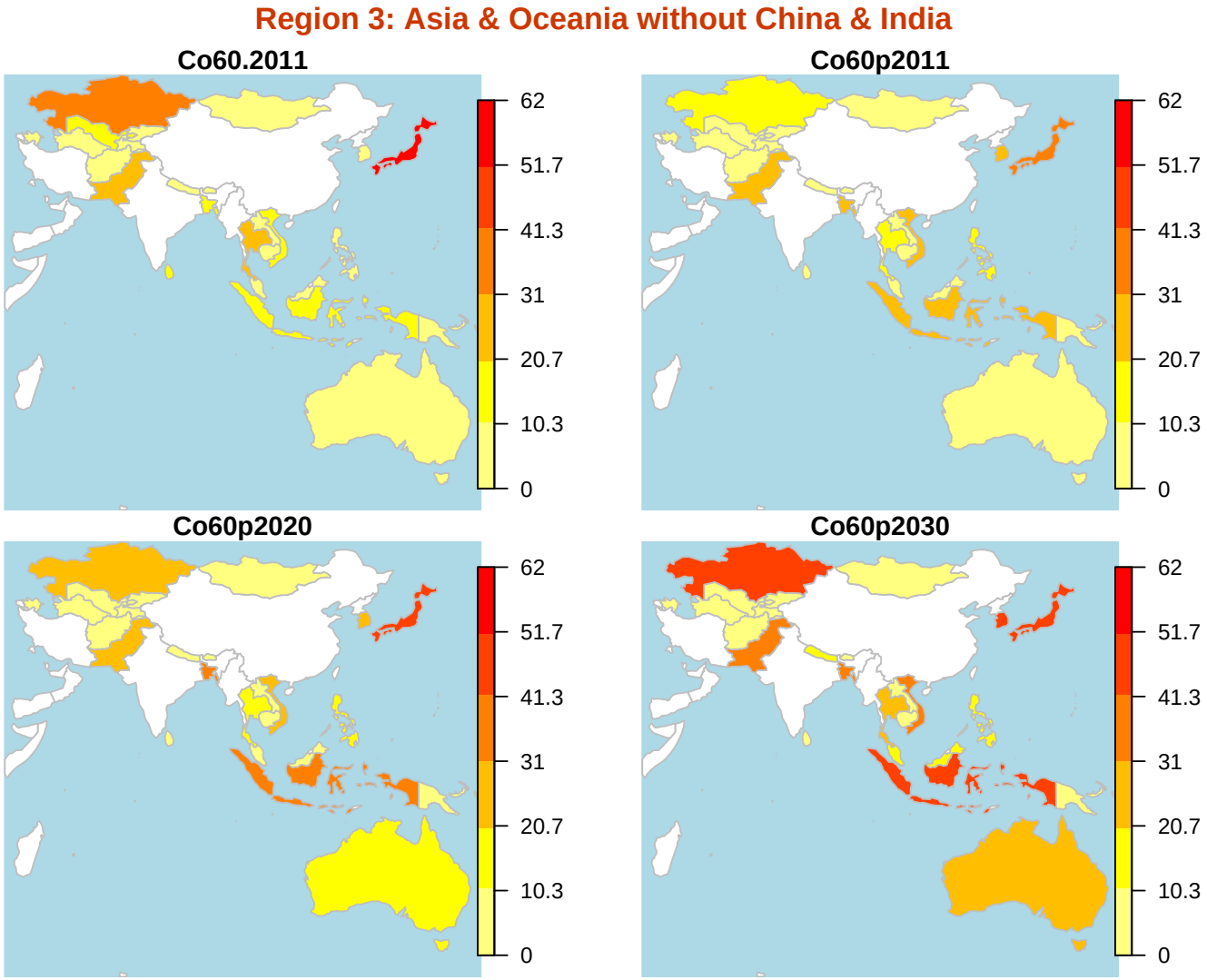

Figure 16: Asia and Oceania without China and India

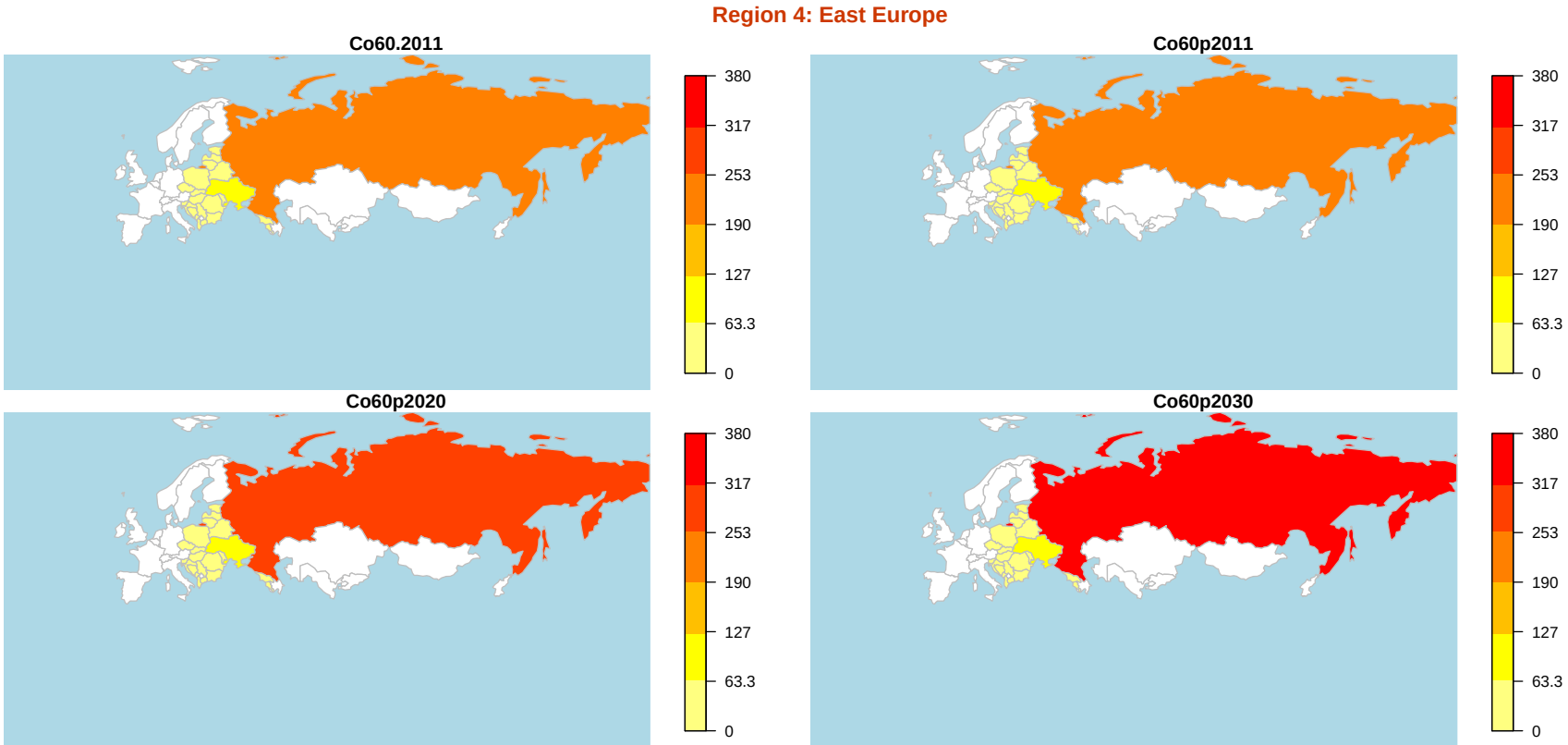

Figure 17: East Europe all

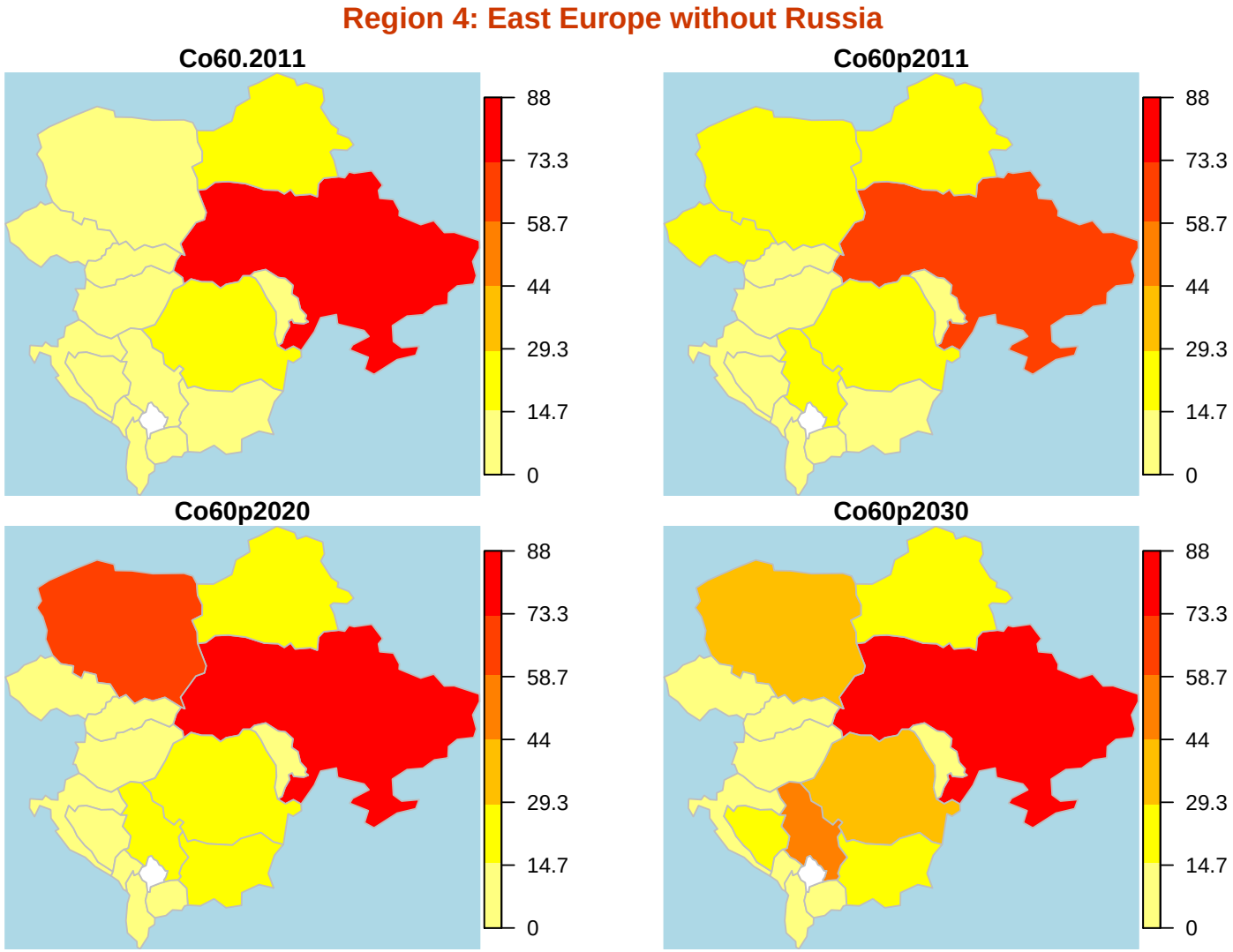

Figure 18: East Europe without Russia

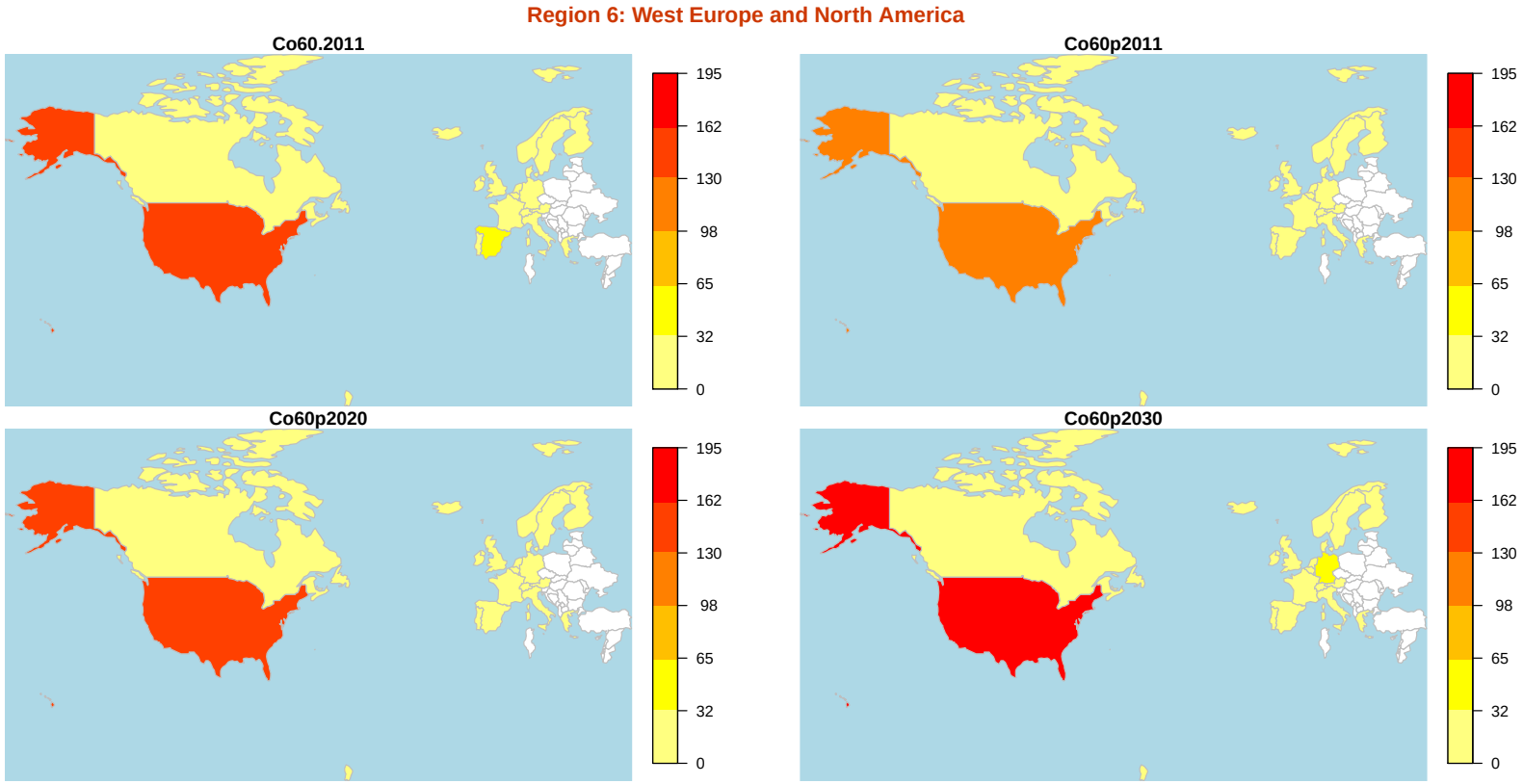

Figure 19: West Europe and North America all

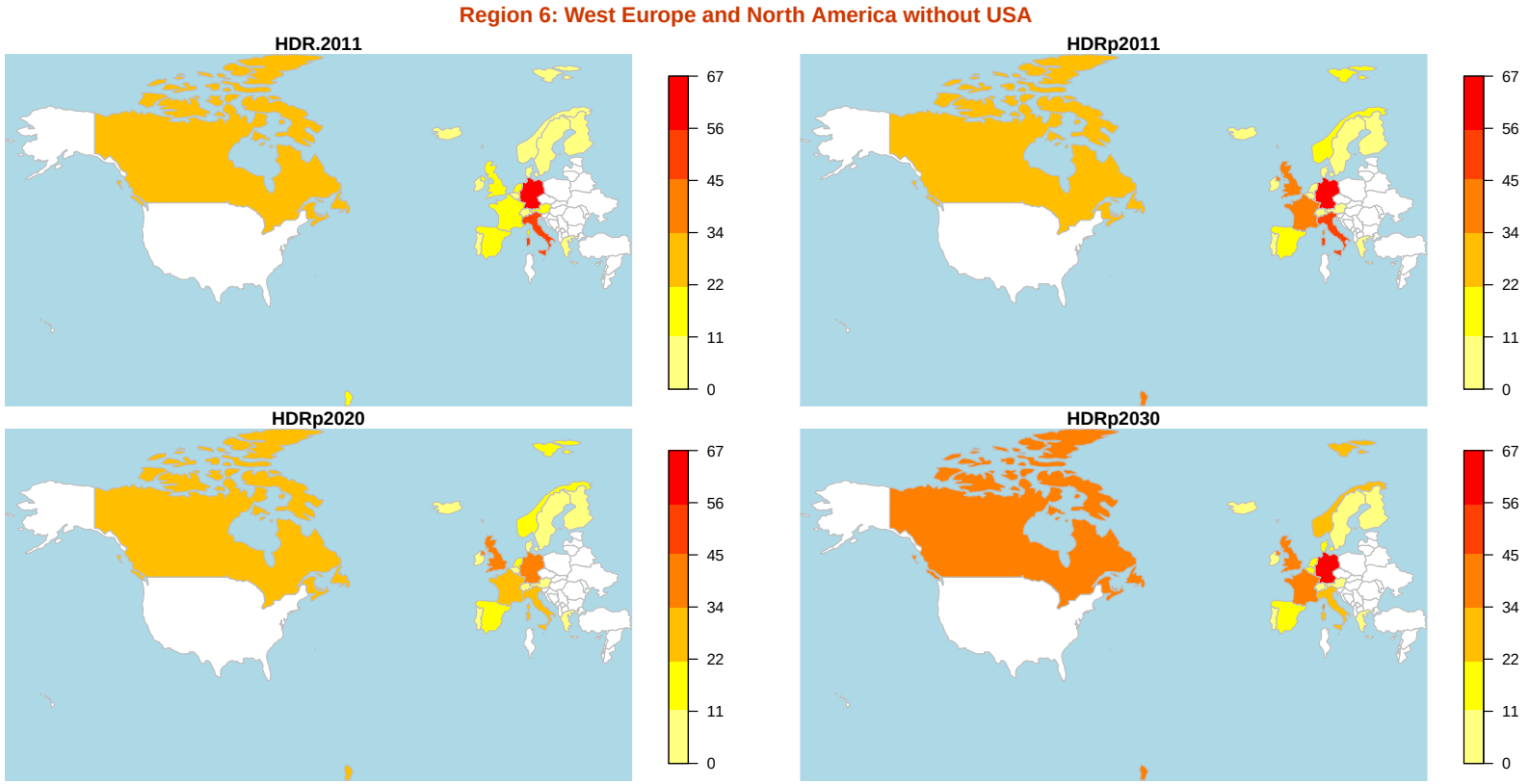

Figure 20: West Europe and North America without USA

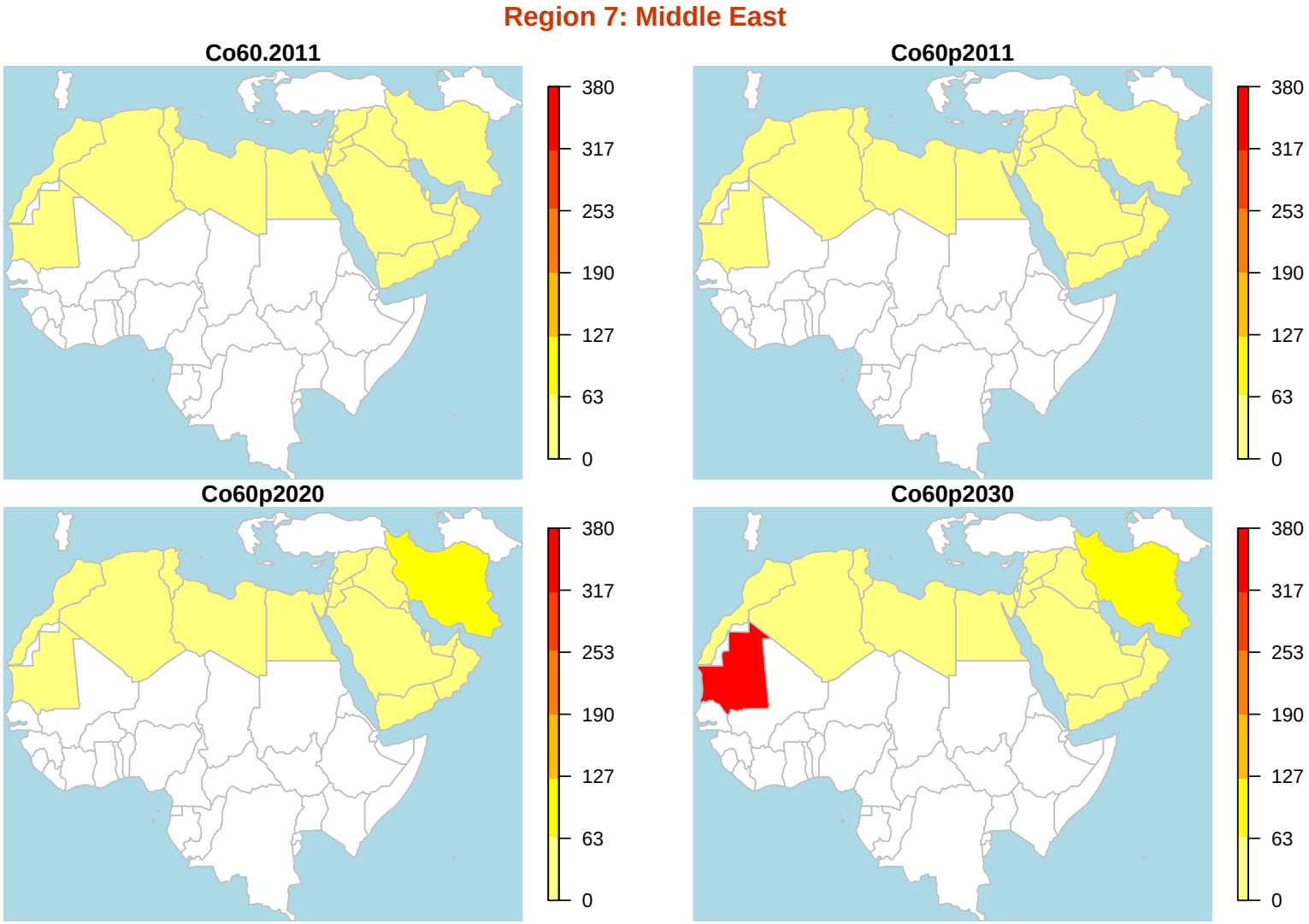

Figure 21: Middle East all

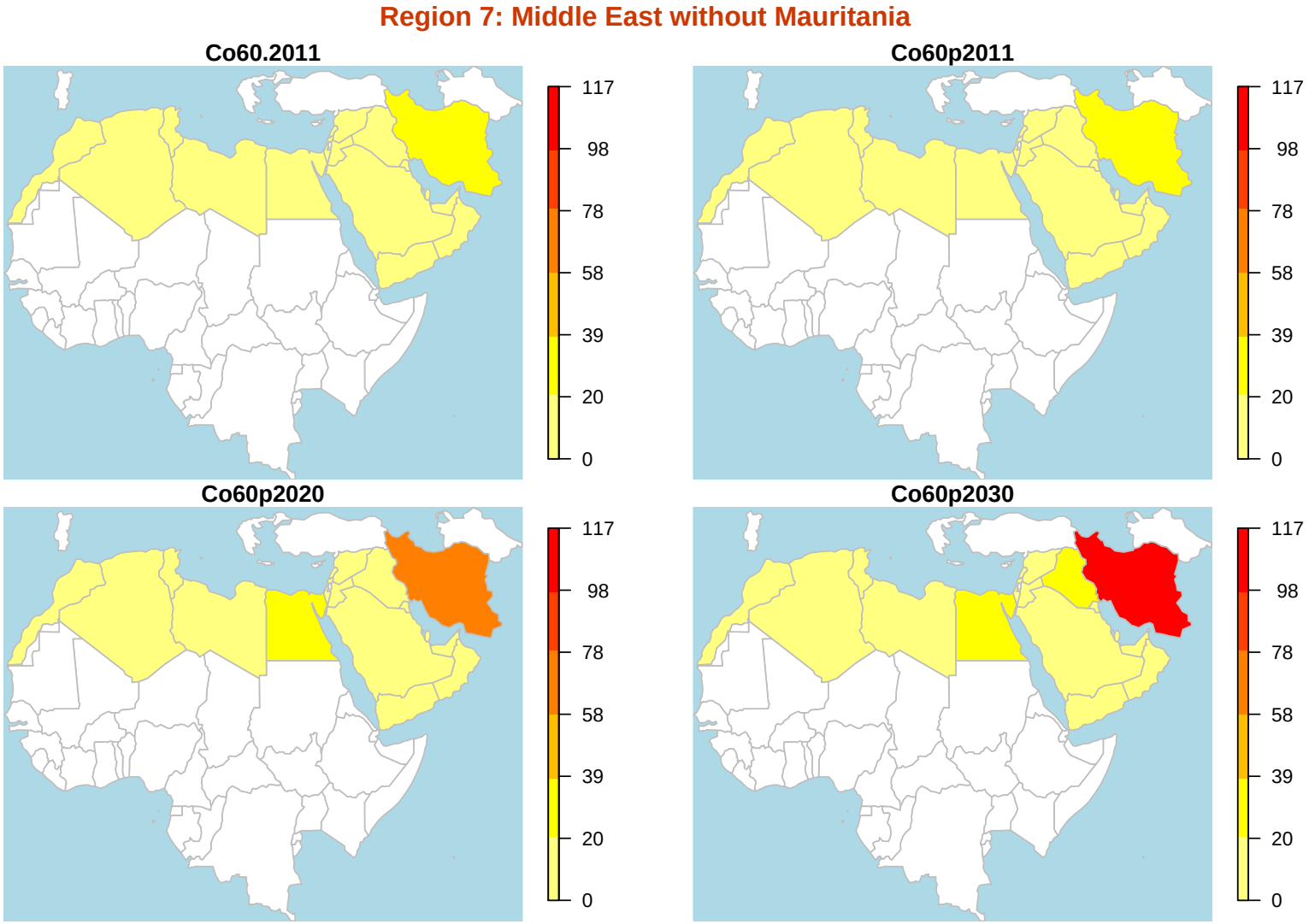

Figure 22: Middle East without Mauritania

Results (Modeling HDR)

```
glm(formula = HDR ~ CPI + CRUPT + factor(H.Type) + factor(region) +
    gdp + log(age) + logCR + logitHDI + popTotal + factor(region):logitHDI,
    family = quasipoisson(link = "log"), data = final)

Deviance Residuals:
    Min       1Q   Median       3Q      Max
-6.6284  -0.8048  -0.2032   0.5846   5.9289

Coefficients:
                              Estimate Std. Error t value Pr(>|t|)
(Intercept)                 -5.374e+00  9.152e-01  -5.873 3.01e-08 ***
CPI                         -5.718e-01  1.912e-01  -2.991 0.003291 **
CRUPT                        1.314e+00  4.064e-01   3.233 0.001532 **
factor(H.Type)S             -9.059e-01  2.388e-01  -3.794 0.000221 ***
factor(region)2             -1.405e+00  6.374e-01  -2.205 0.029134 *
factor(region)3             -1.975e+00  5.509e-01  -3.585 0.000466 ***
factor(region)4             -9.299e-01  7.065e-01  -1.316 0.190220
factor(region)5             -4.889e-03  4.621e+00  -0.001 0.999157
factor(region)6             -1.683e+00  1.303e+00  -1.292 0.198517
factor(region)7             -1.901e+00  7.332e-01  -2.593 0.010524 *
gdp                          3.216e-05  7.353e-06   4.374 2.38e-05 ***
log(age)                    -3.061e-01  7.214e-02  -4.243 4.01e-05 ***
logCR                        1.178e+00  6.342e-02  18.574  < 2e-16 ***
logitHDI                    -1.317e+00  7.943e-01  -1.657 0.099674 .
popTotal                    -9.852e-07  2.915e-07  -3.380 0.000941 ***
factor(region)2:logitHDI     6.882e+00  1.731e+00   3.975 0.000112 ***
factor(region)3:logitHDI     1.951e+00  8.235e-01   2.369 0.019213 *
factor(region)4:logitHDI     9.705e-01  9.910e-01   0.979 0.329129
factor(region)5:logitHDI     1.194e+00  5.776e+00   0.207 0.836566
factor(region)6:logitHDI     8.588e-01  1.283e+00   0.669 0.504370
factor(region)7:logitHDI     2.103e+00  1.079e+00   1.949 0.053317 .
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Signif. codes:  0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

(Dispersion parameter for quasipoisson family taken to be 2.699369)
```

Figure 23: HDR Model: Best AIC Model, Max=332(USA), R^2=0.9313264.

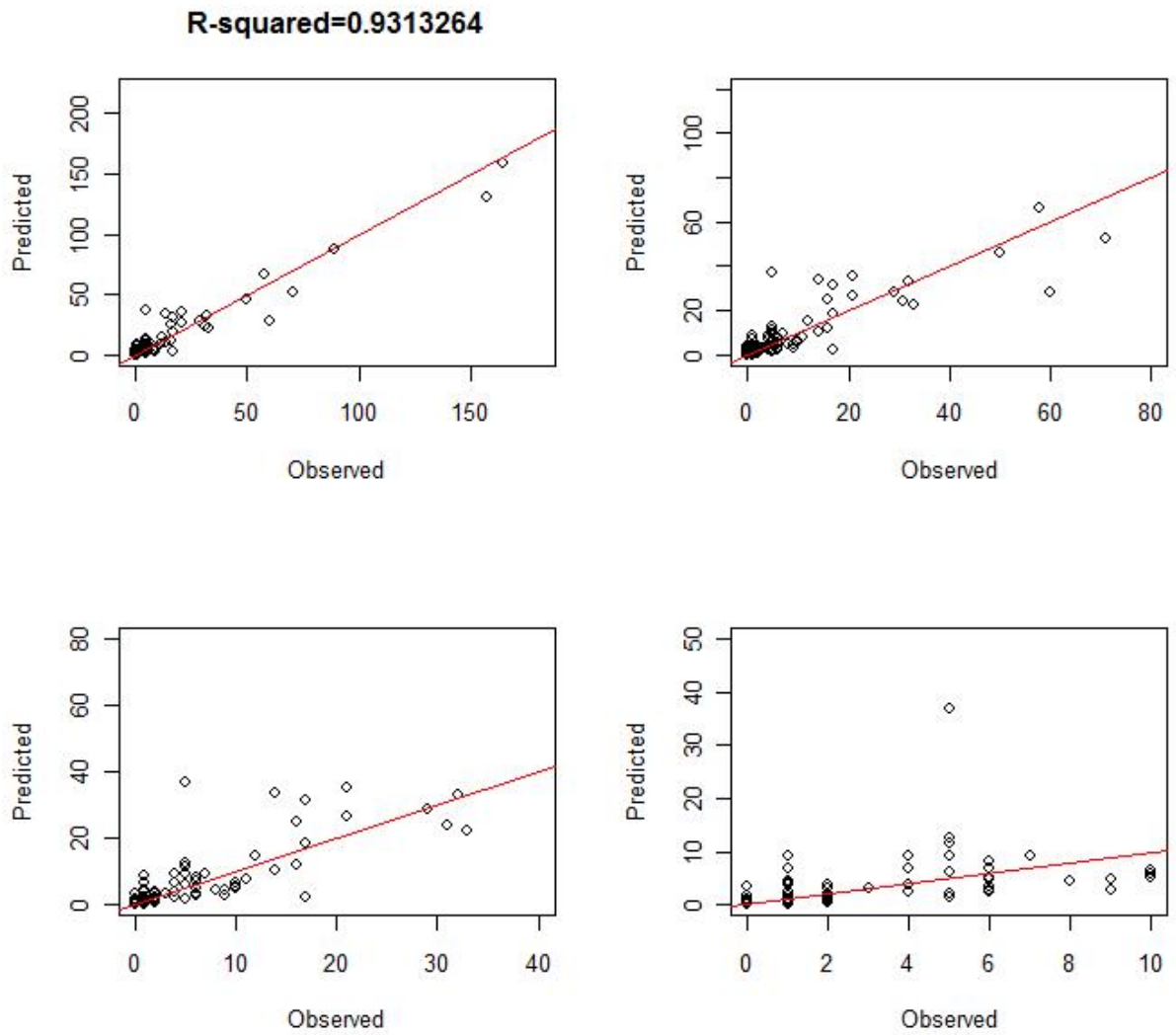

Figure 24: The association between the observed and predicted values of HDR.

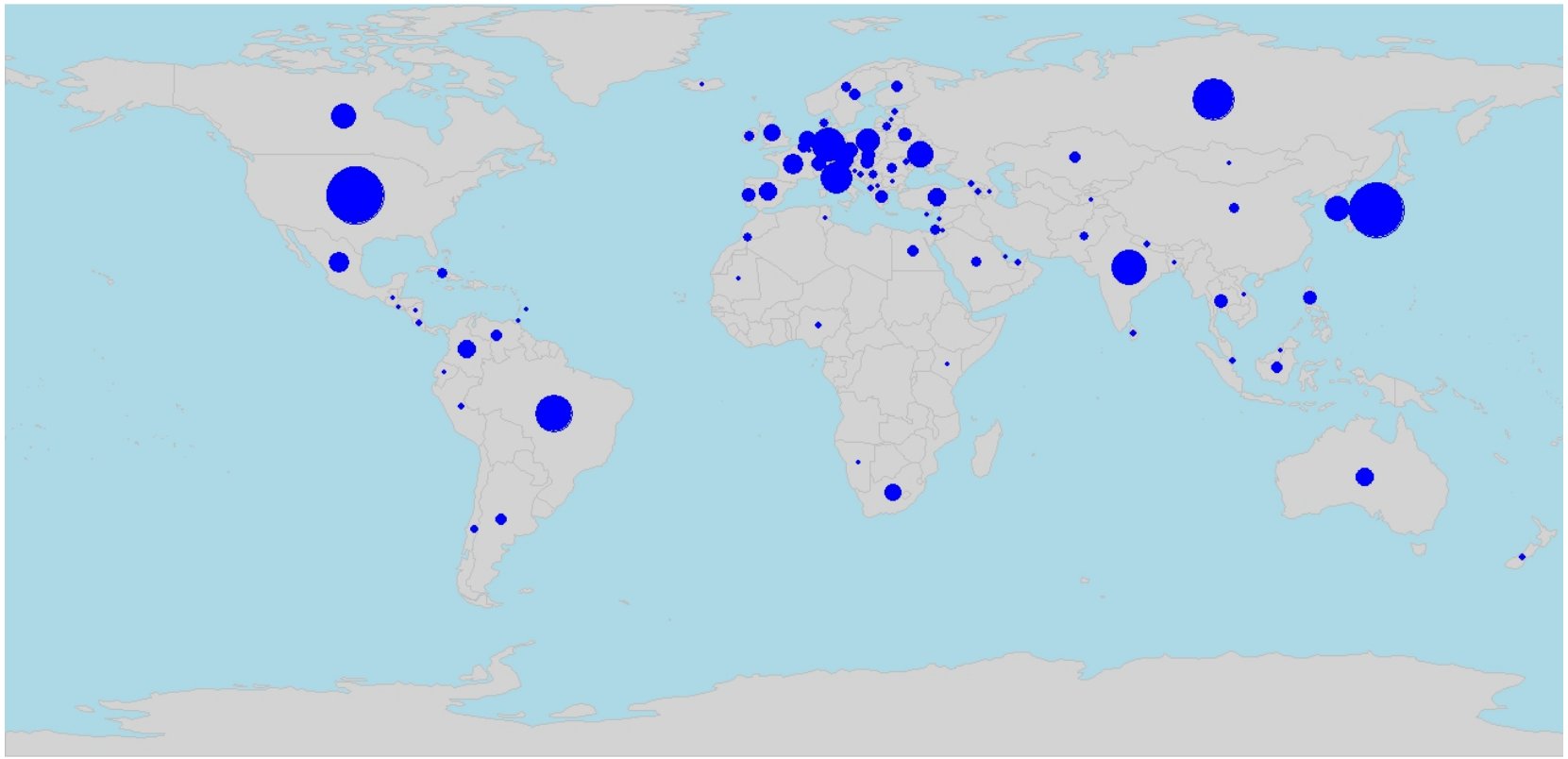

Figure 25: True HDR in 2011

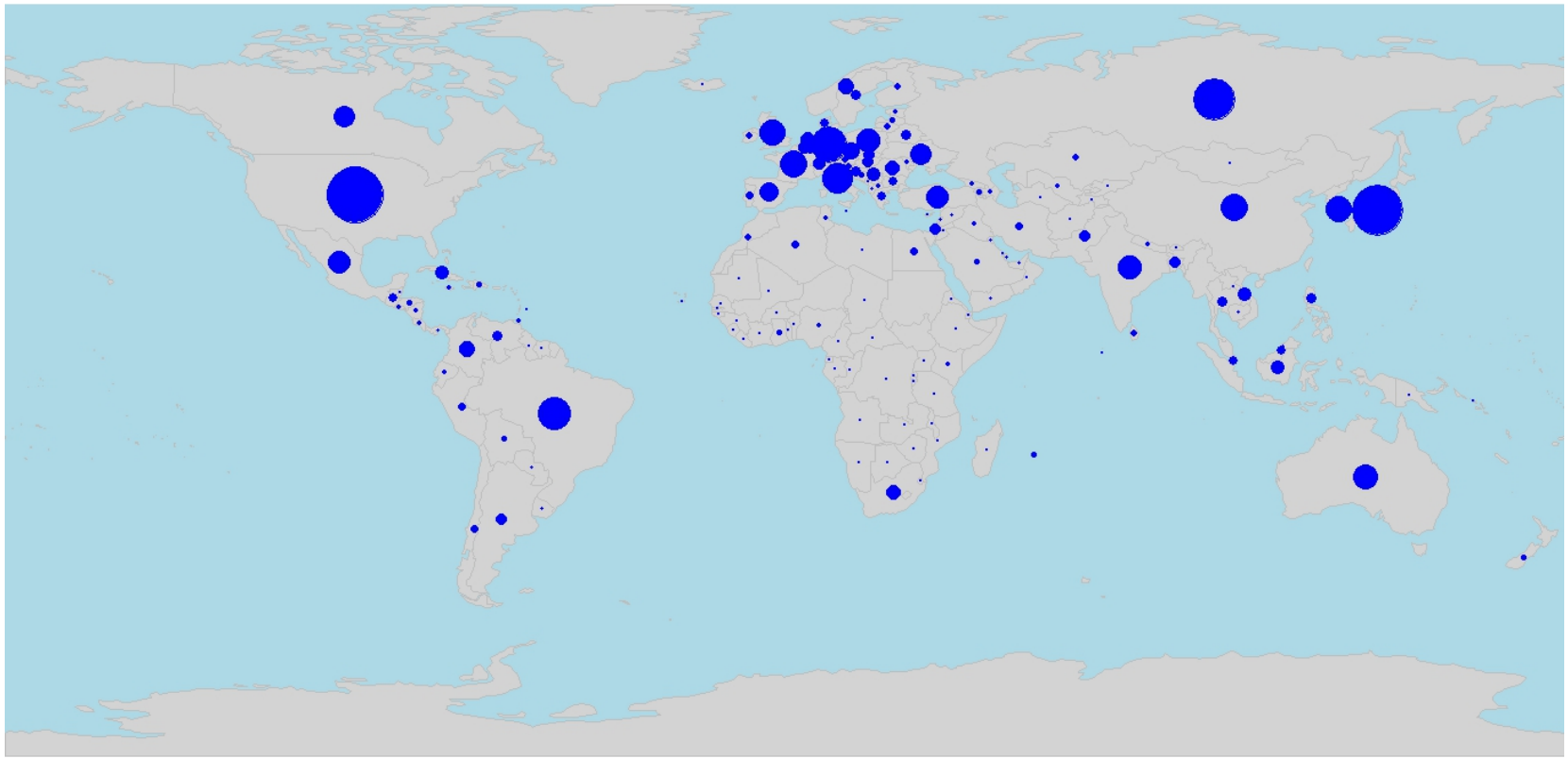

Figure 26: Predictied HDR in 2011

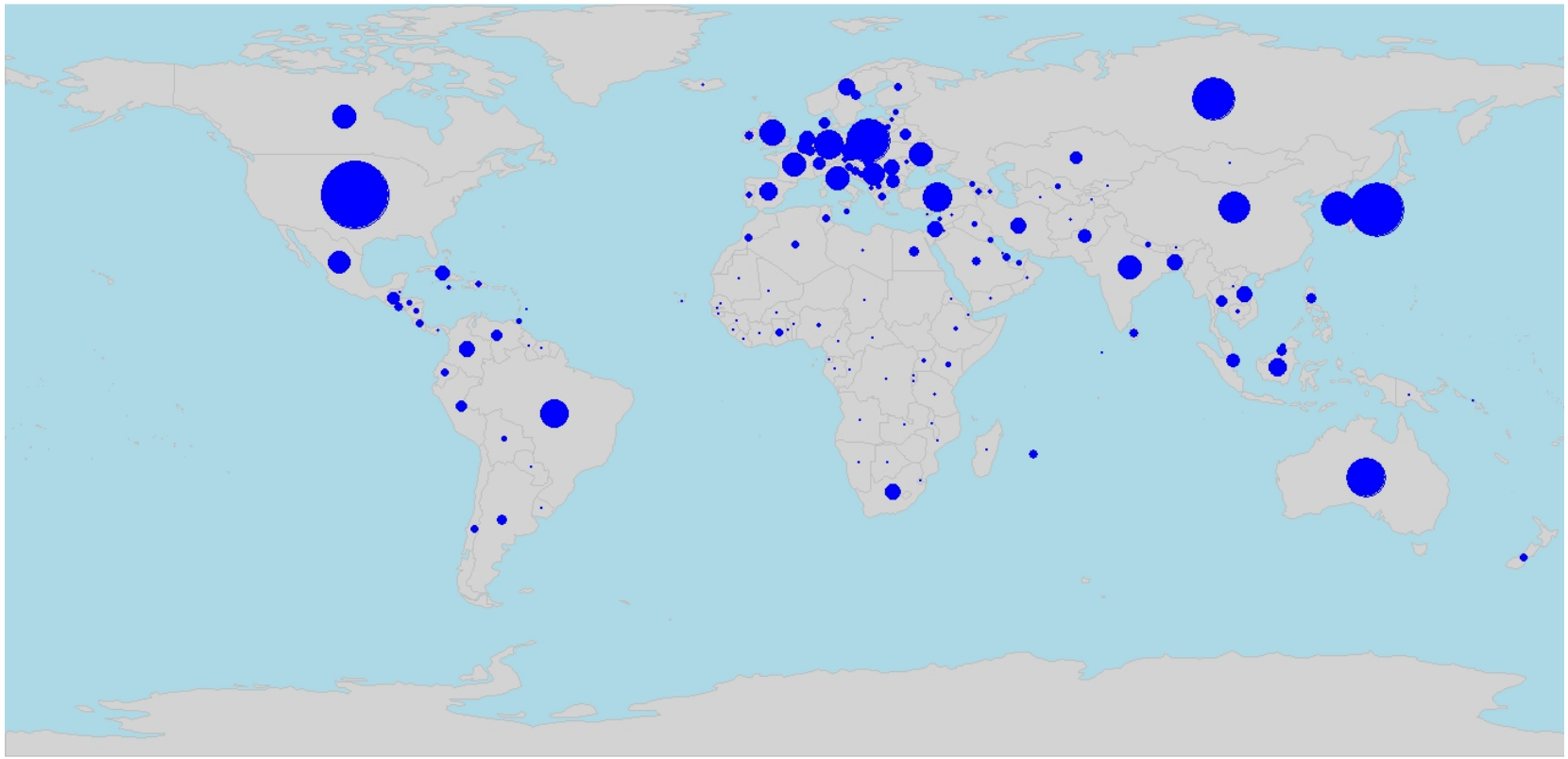

Figure 27: Predicted HDR in 2020

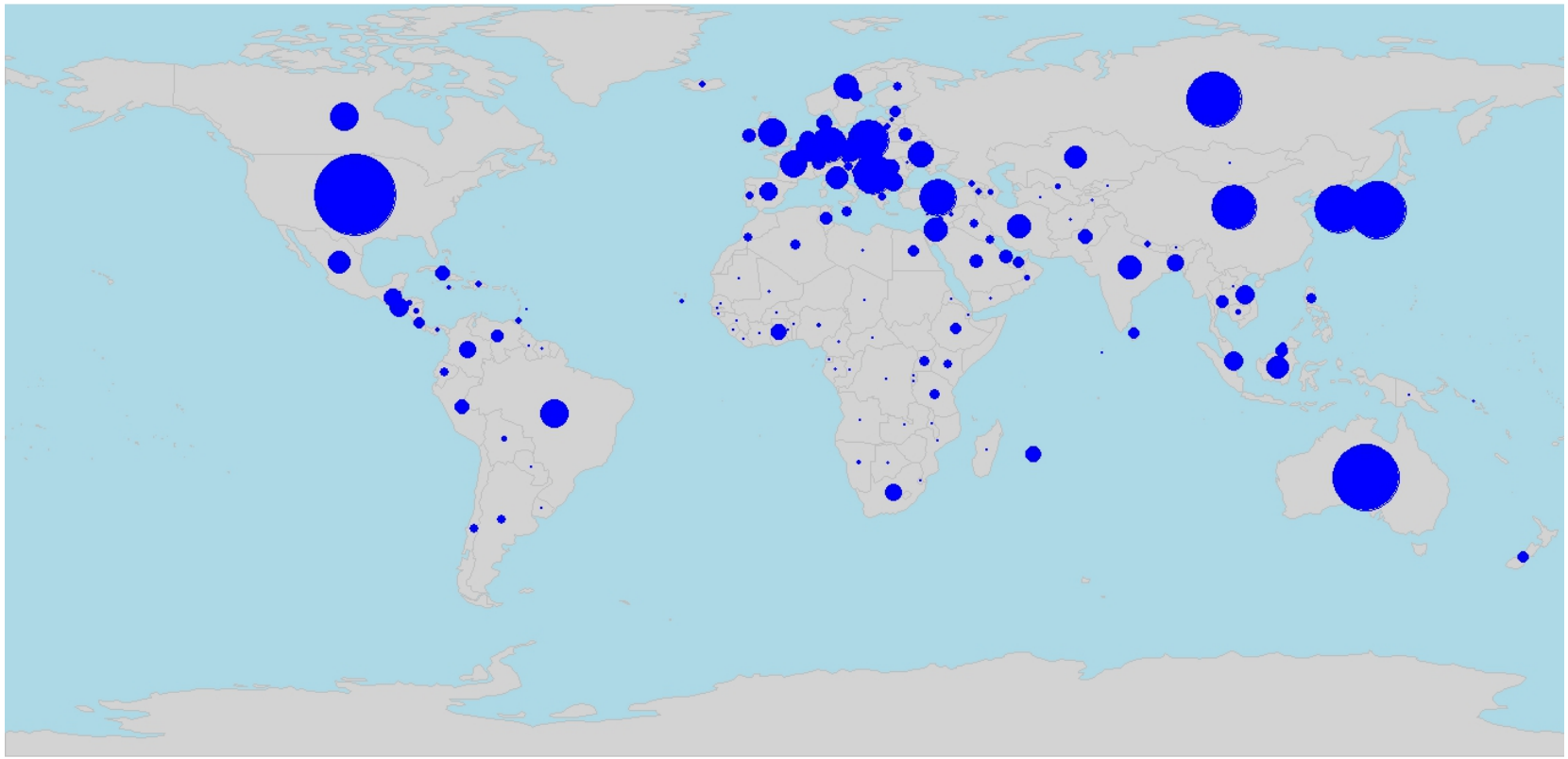

Figure 28: Predicted HDR in 2030

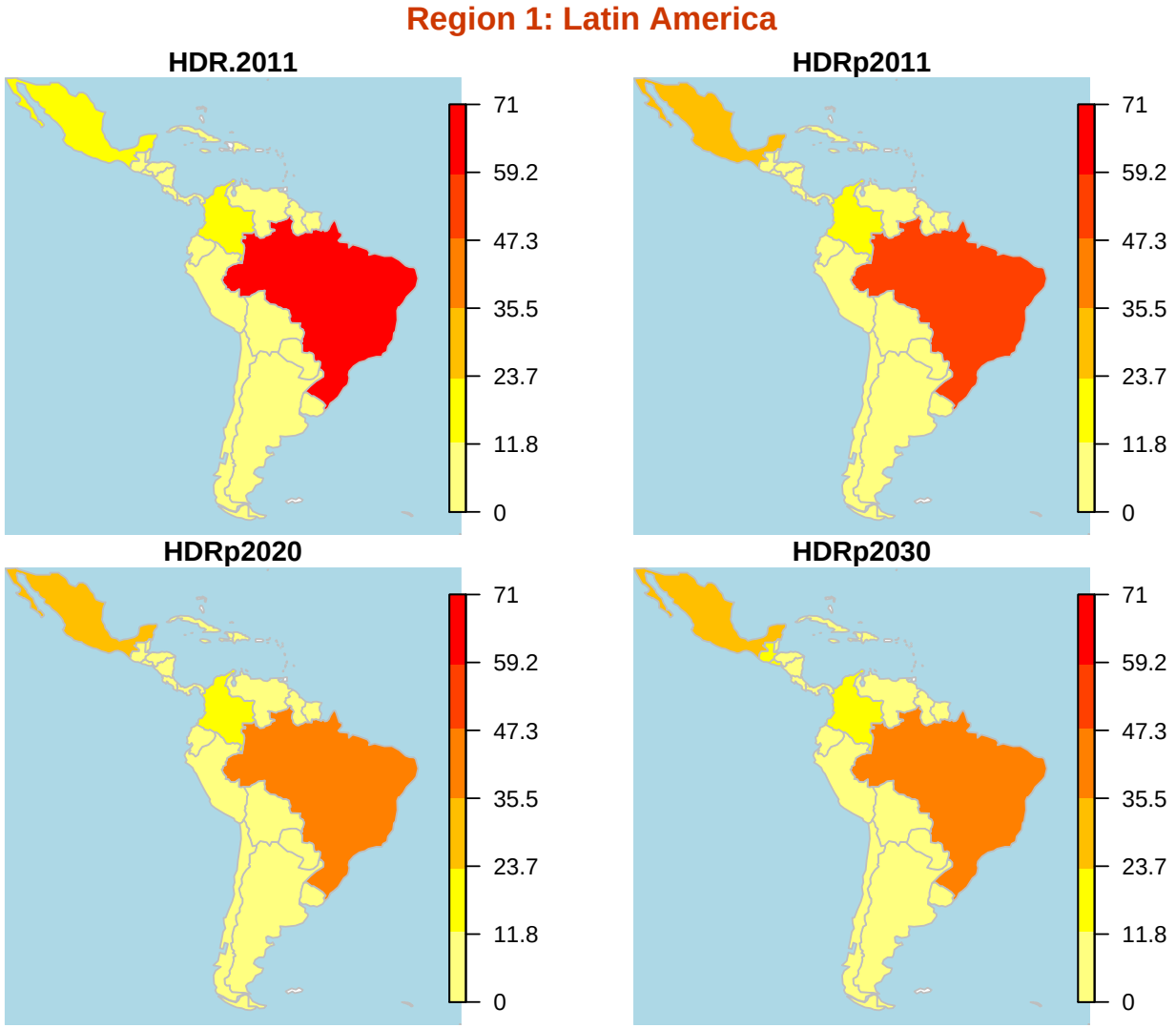

Figure 29: Latin America all

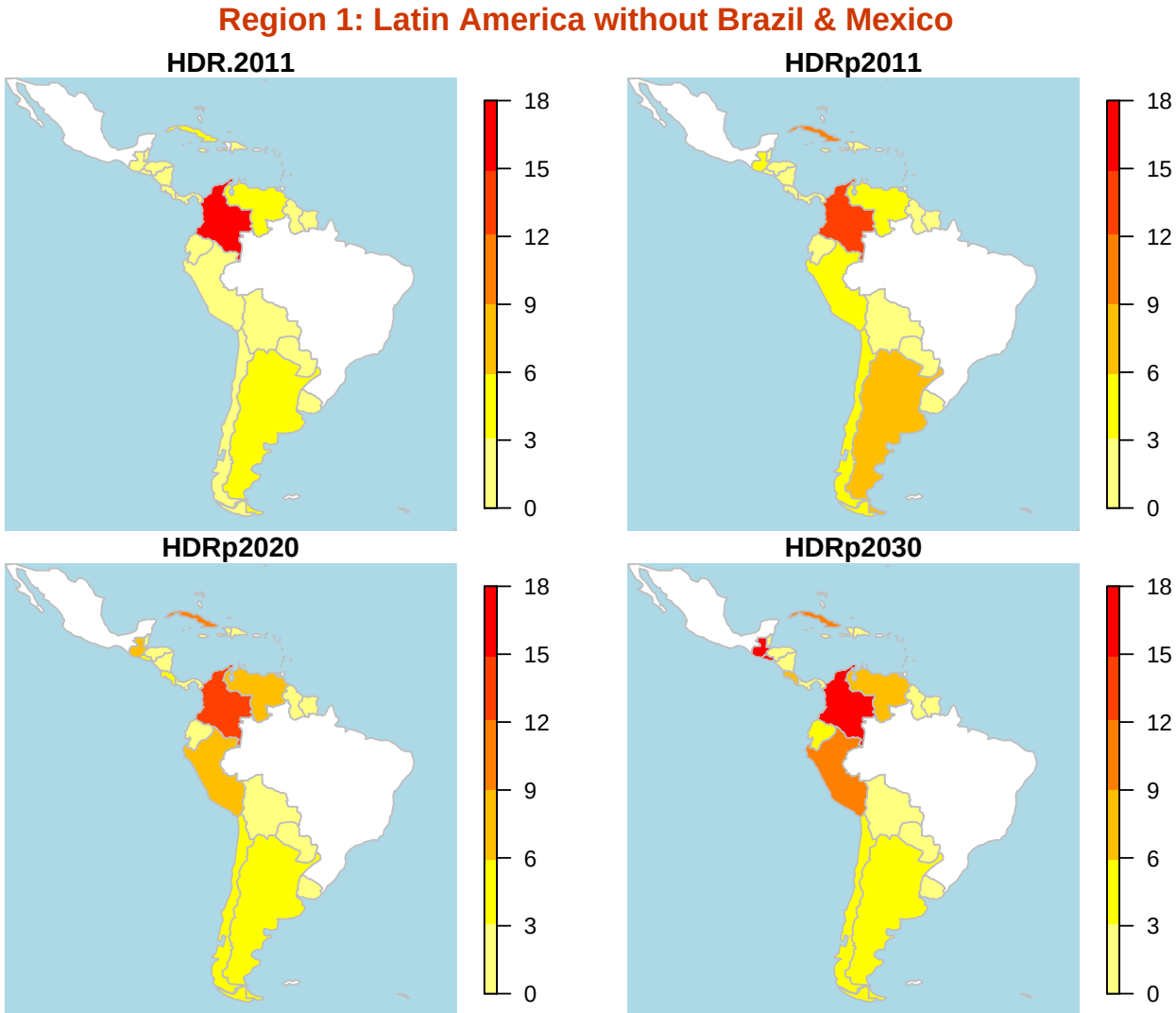

Figure 30: Latin America without Brazil and Mexico

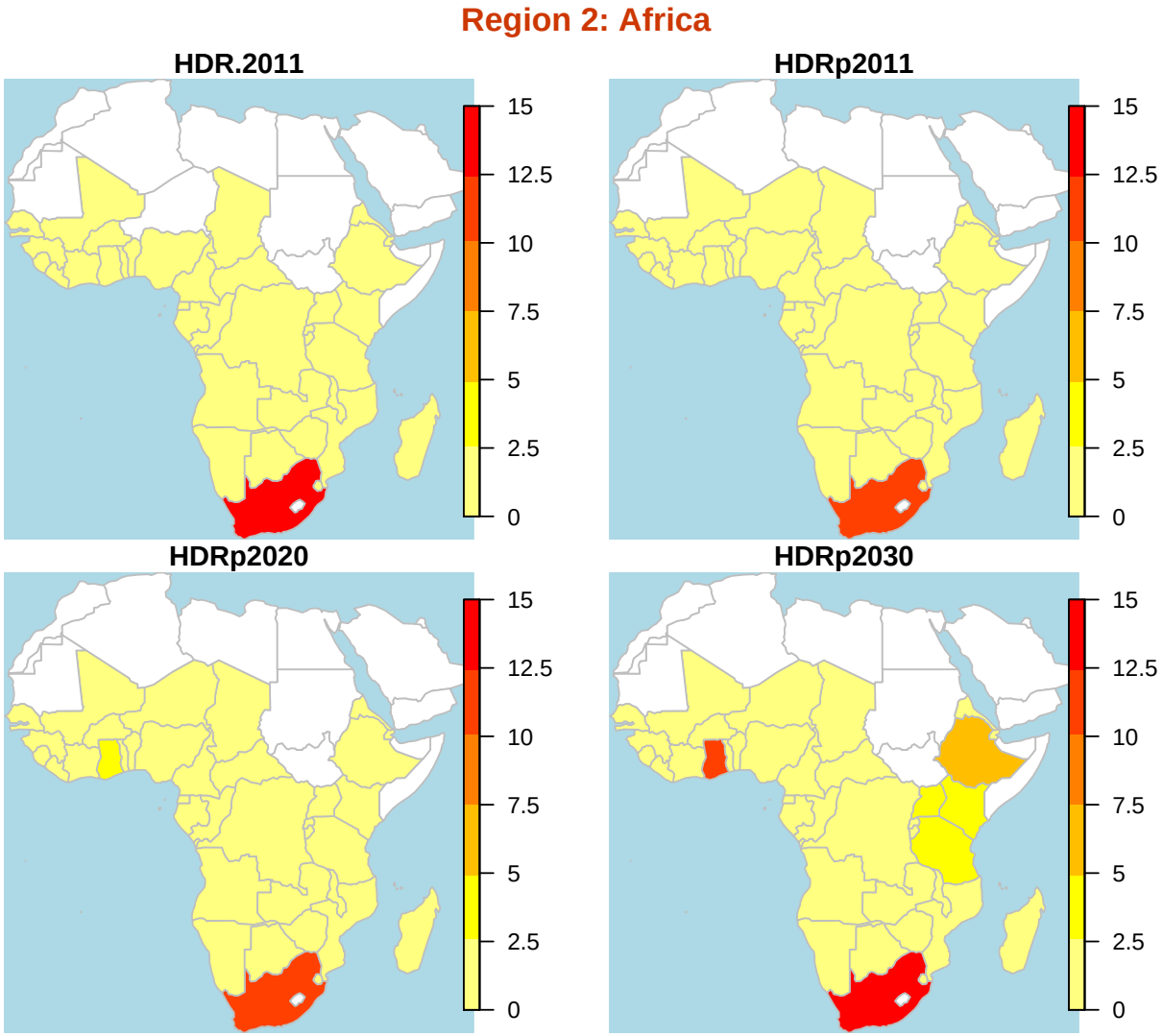

Figure 31: Africa all

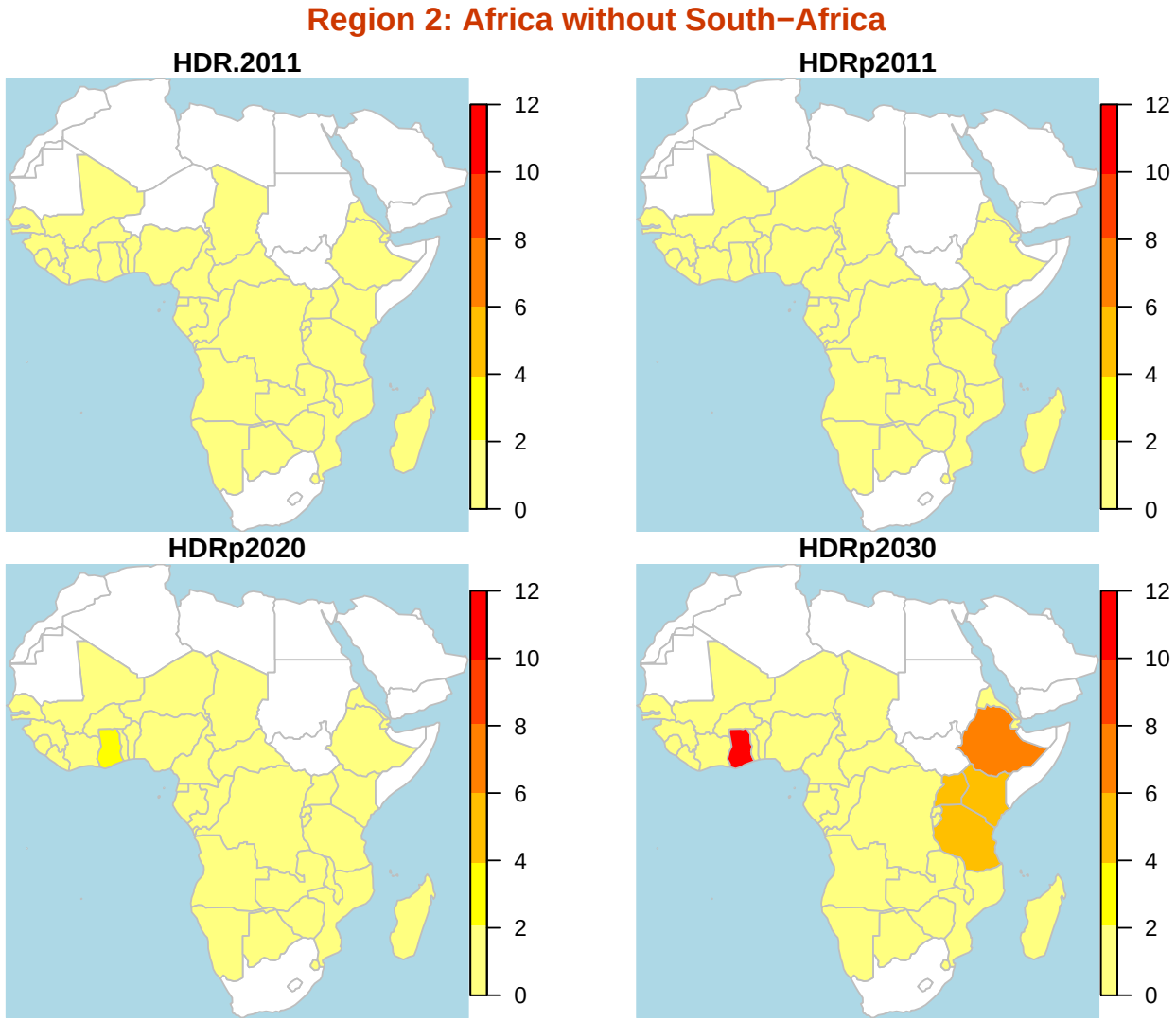

Figure 32: Africa without South-Arfica

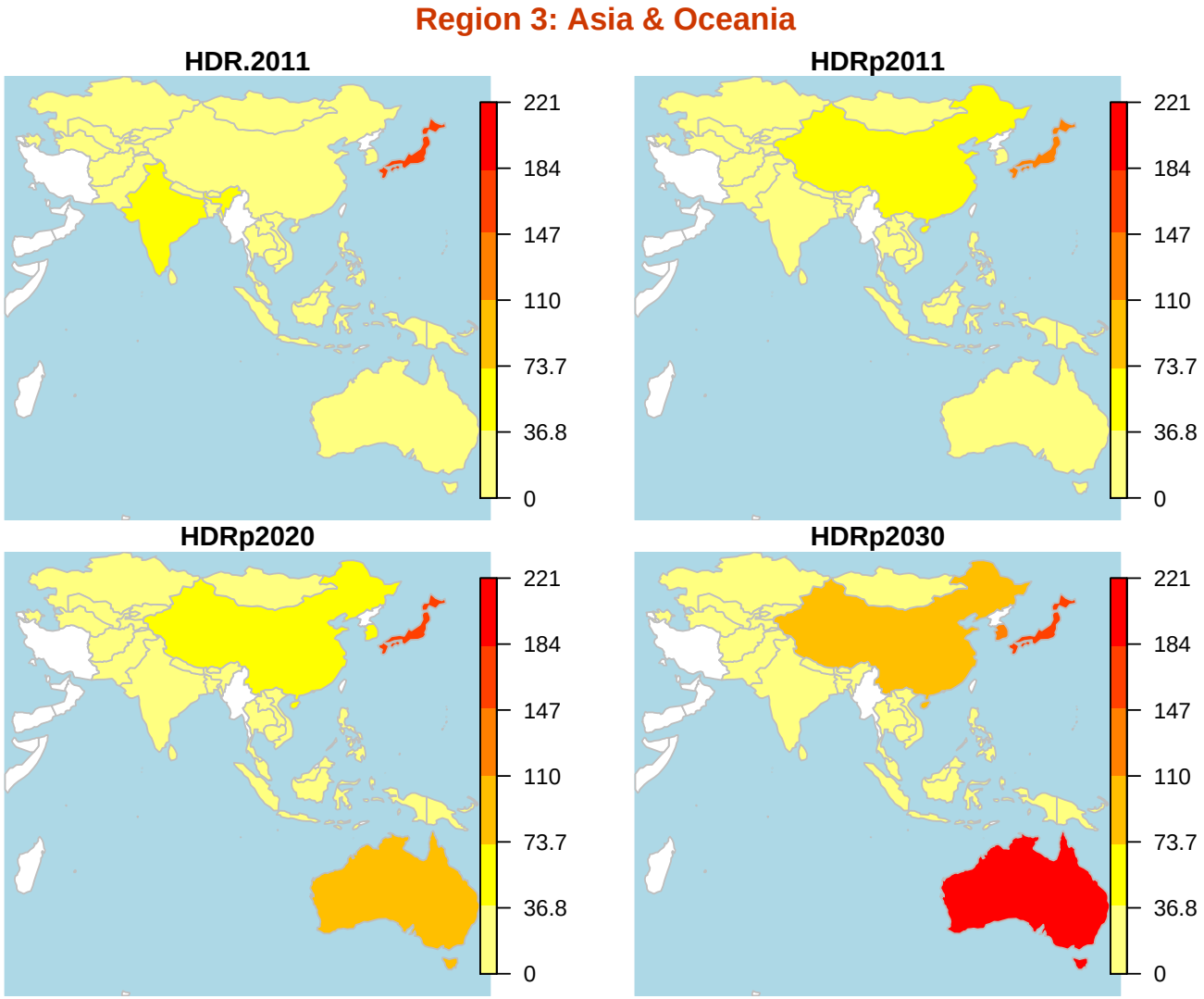

Figure 33: Asia and Oceania all

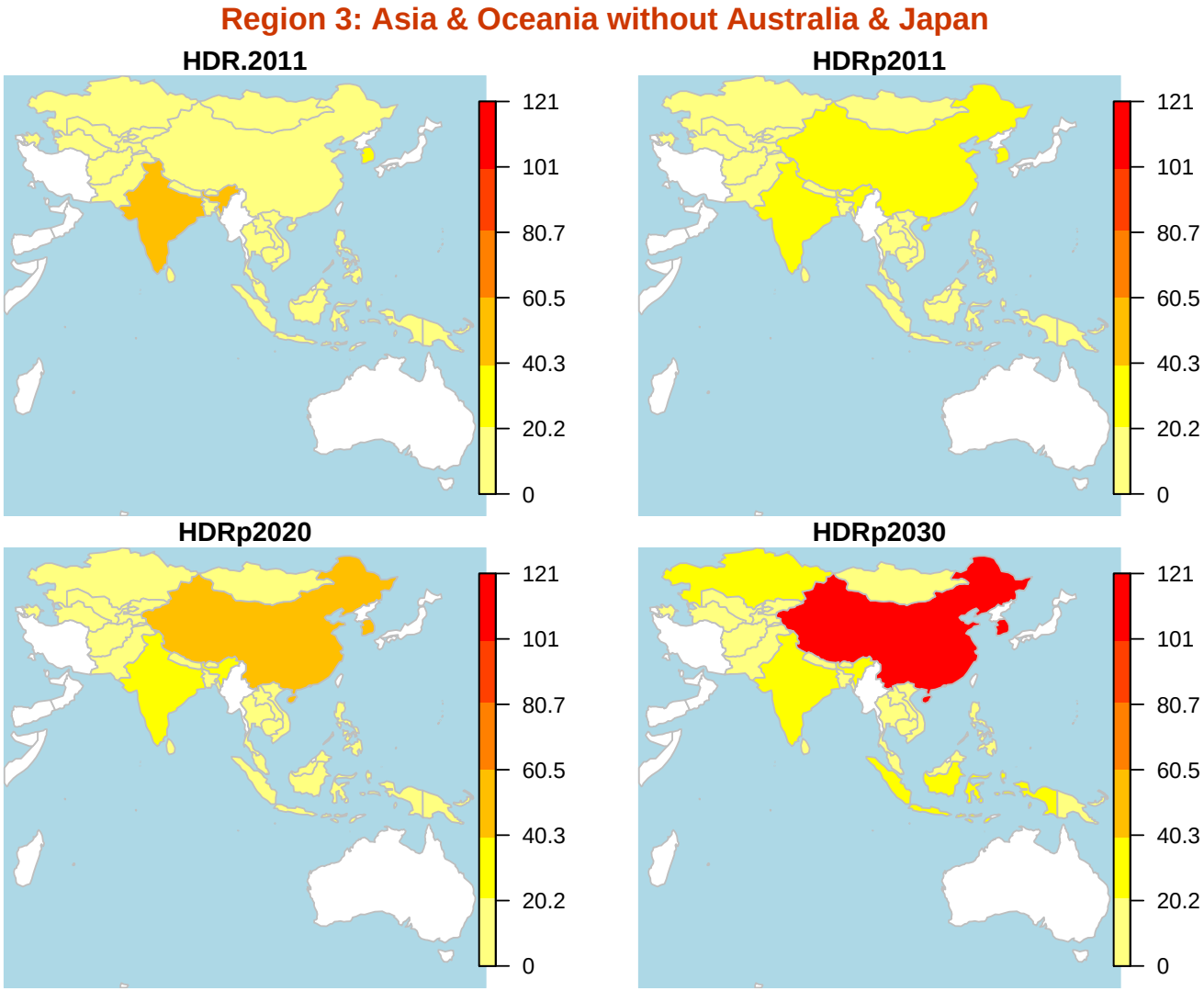

Figure 34: Asia and Oceania without Australia and Japan

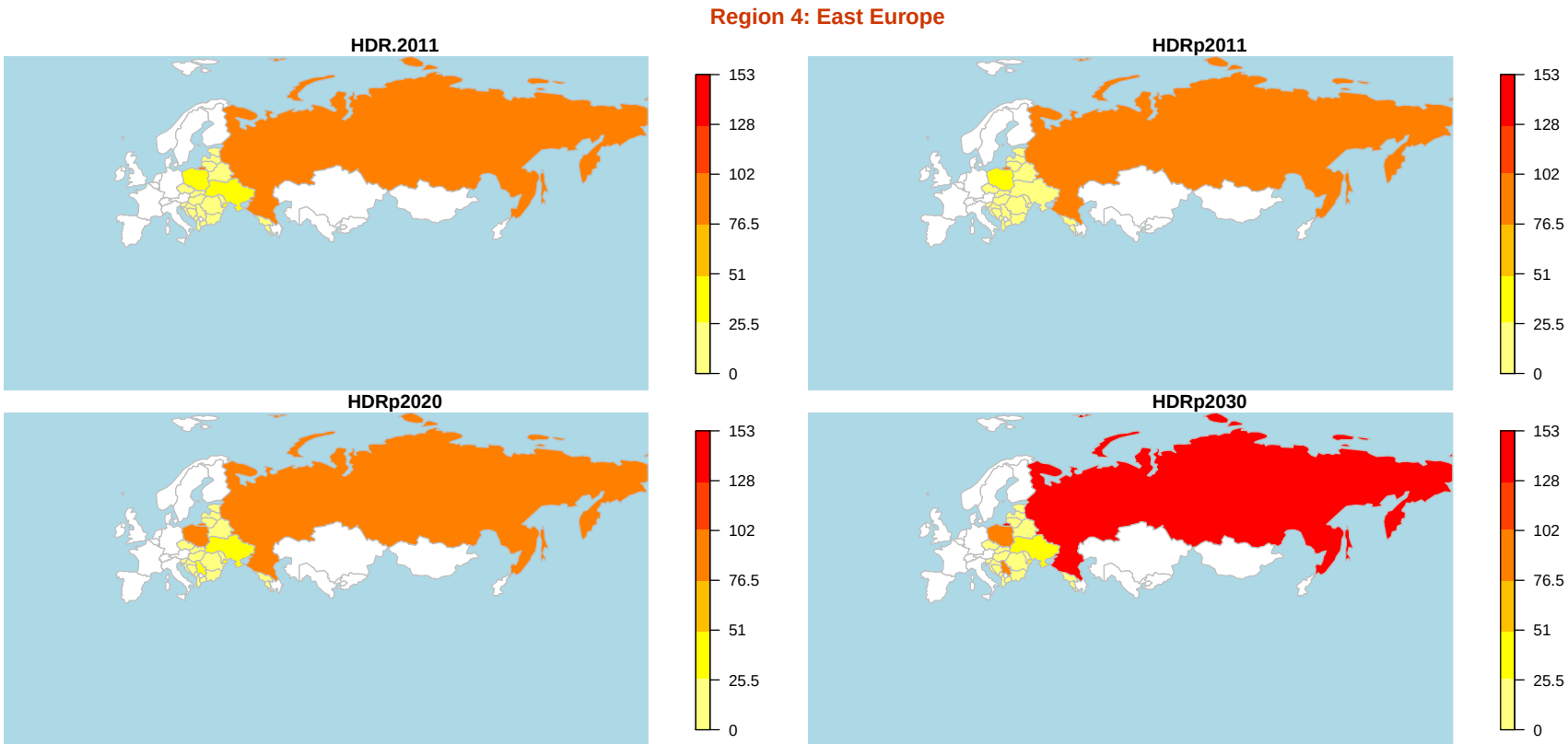

Figure 35: East Europe all

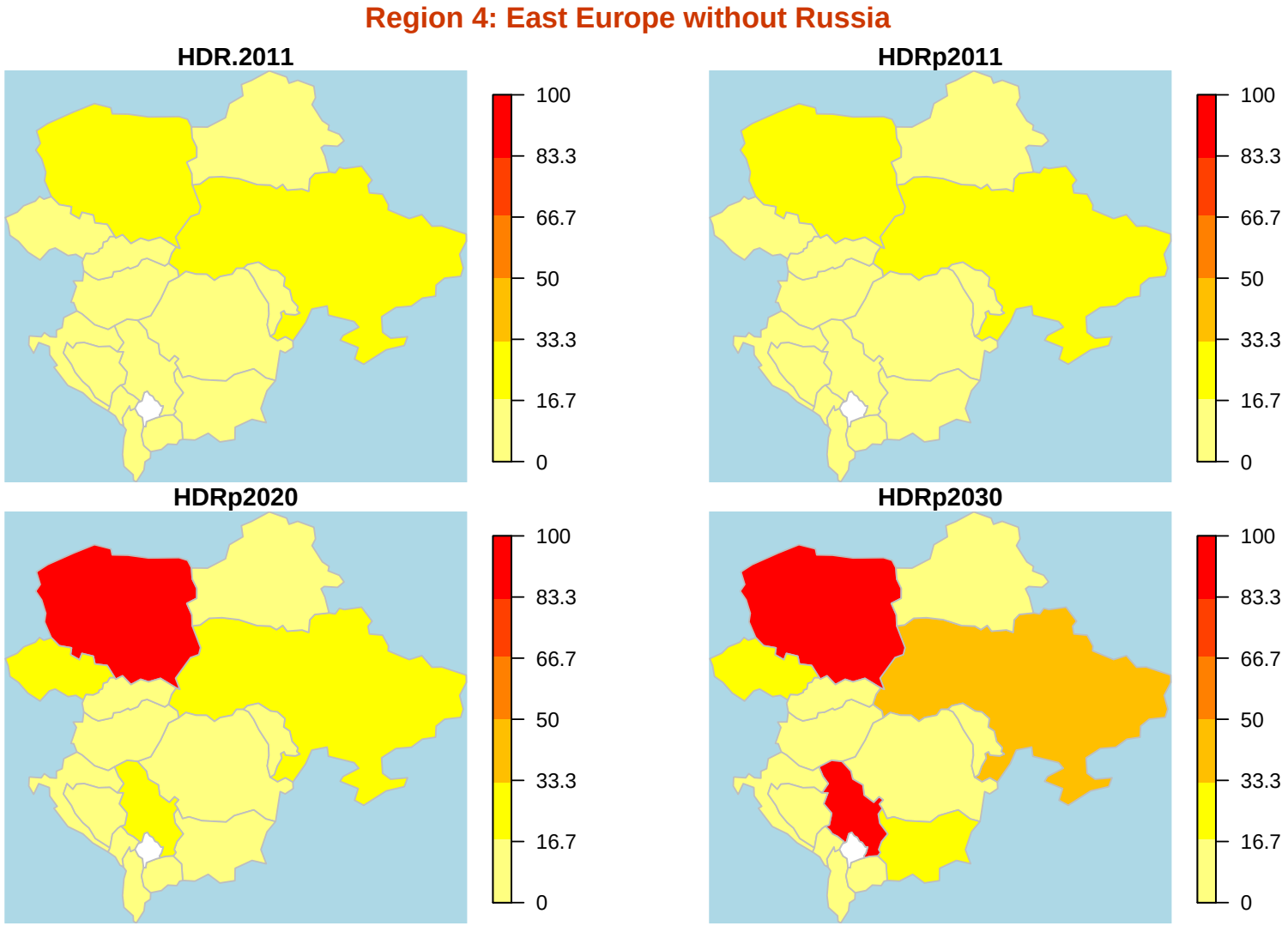

Figure 36: East Europe without Russia

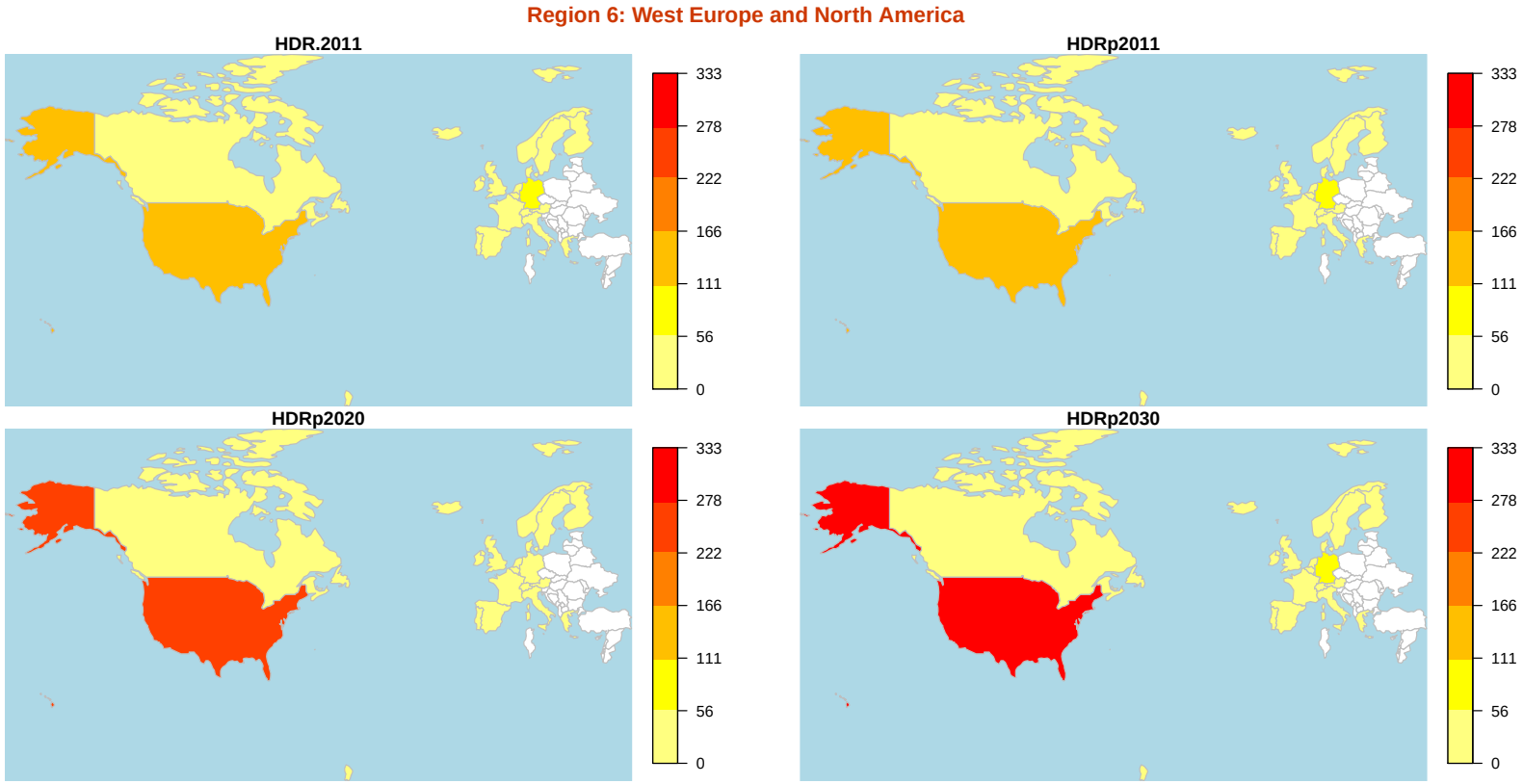

Figure 37: West Europe and North America all

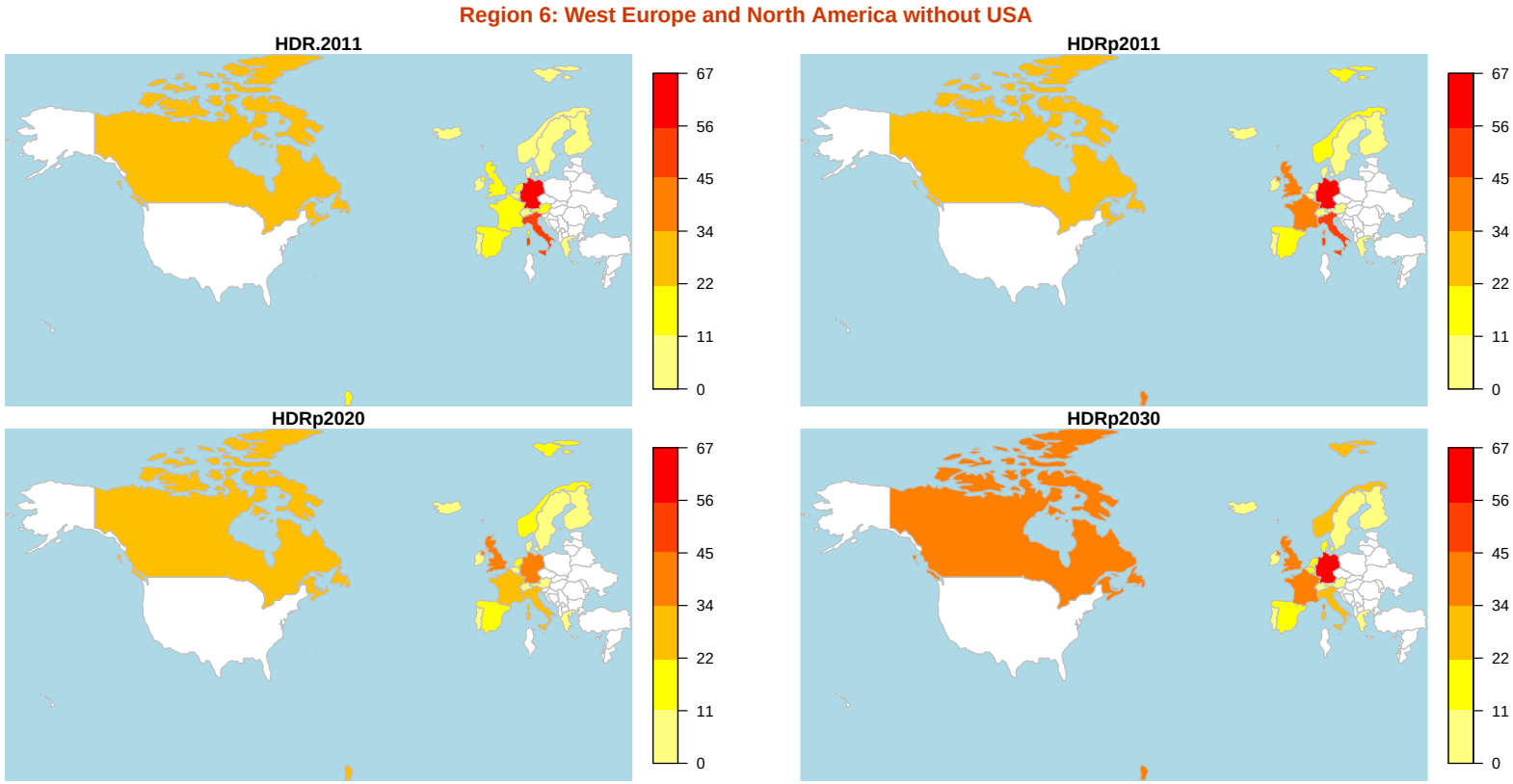

Figure 38: West Europe and North America without USA

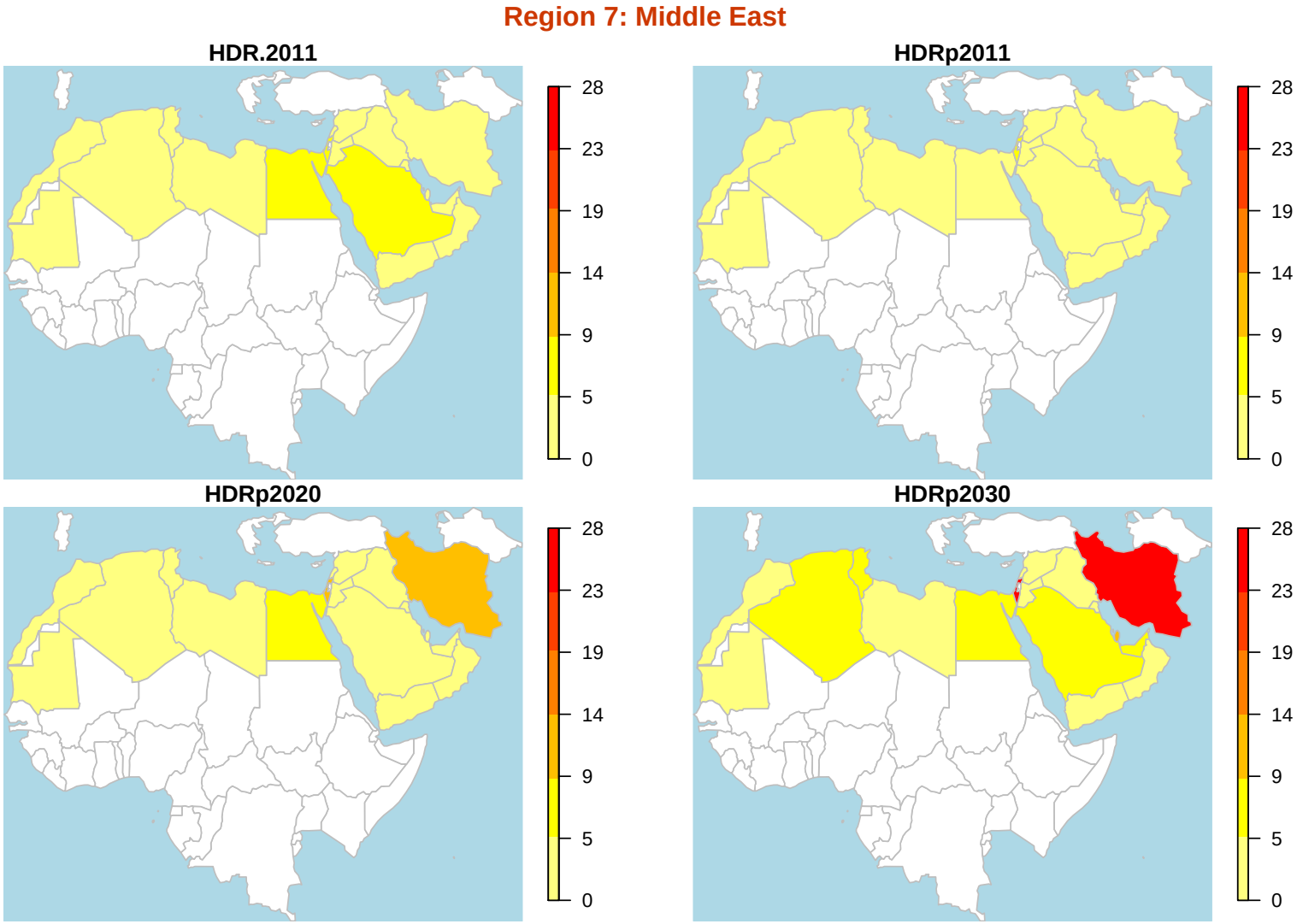

Figure 39: Middle East all

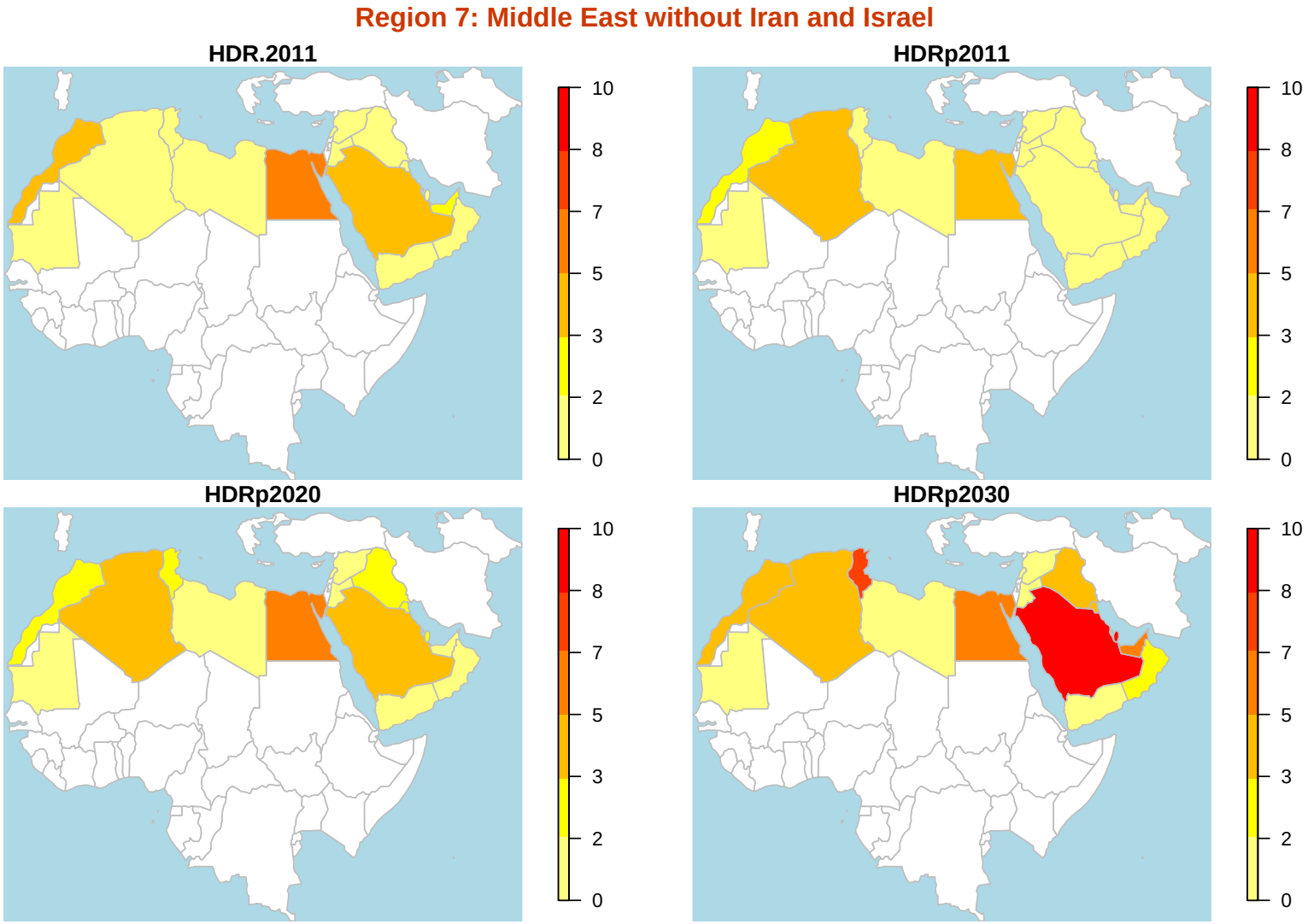

Figure 40: Middle East without Iran and Israel

Conclusion

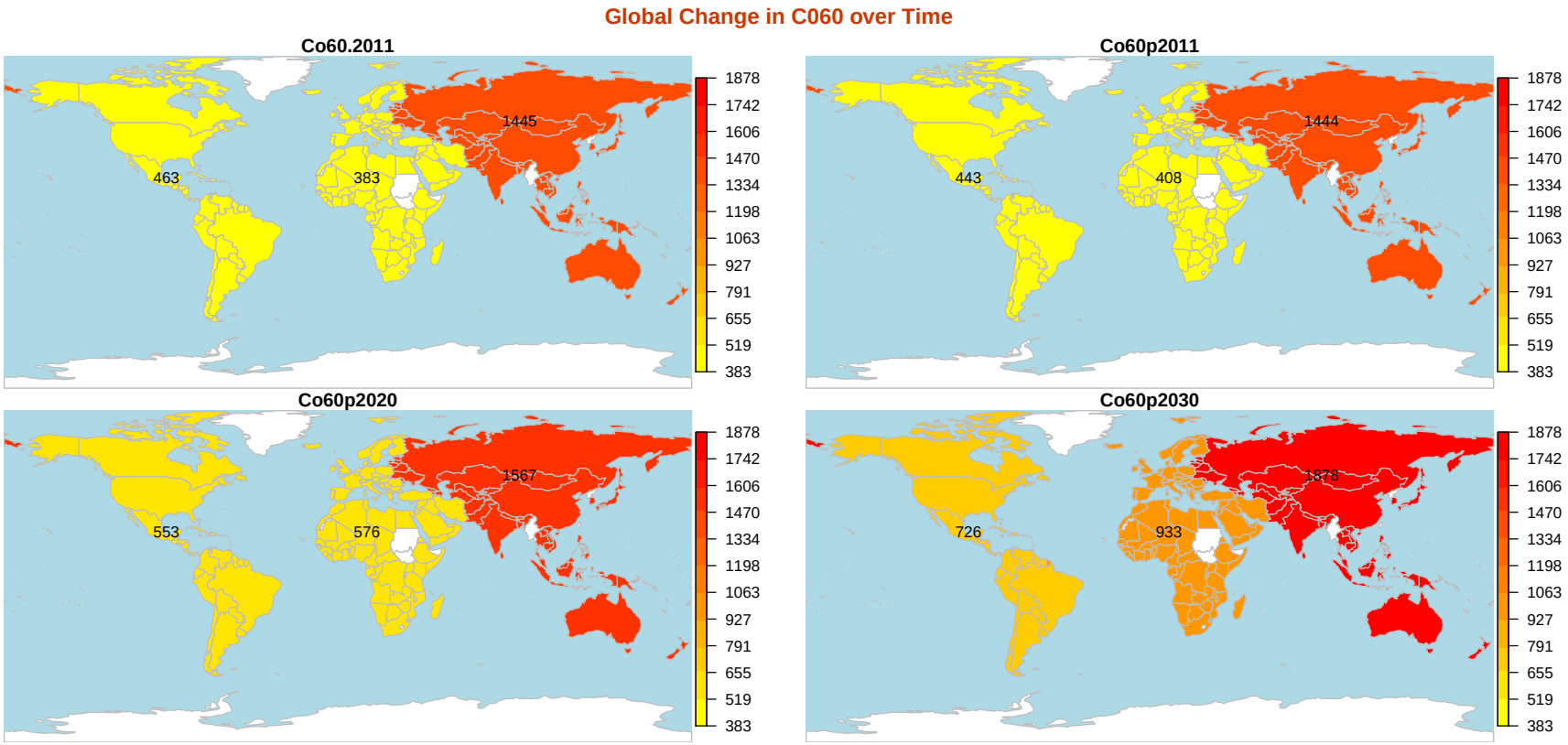

Figure 41: Global map for the actual and predicted values for Co60 for Three Regions (1. North and South America, 2. Europe, Africa and the Middle East, 3. Old USSR, Asia and Oceania).

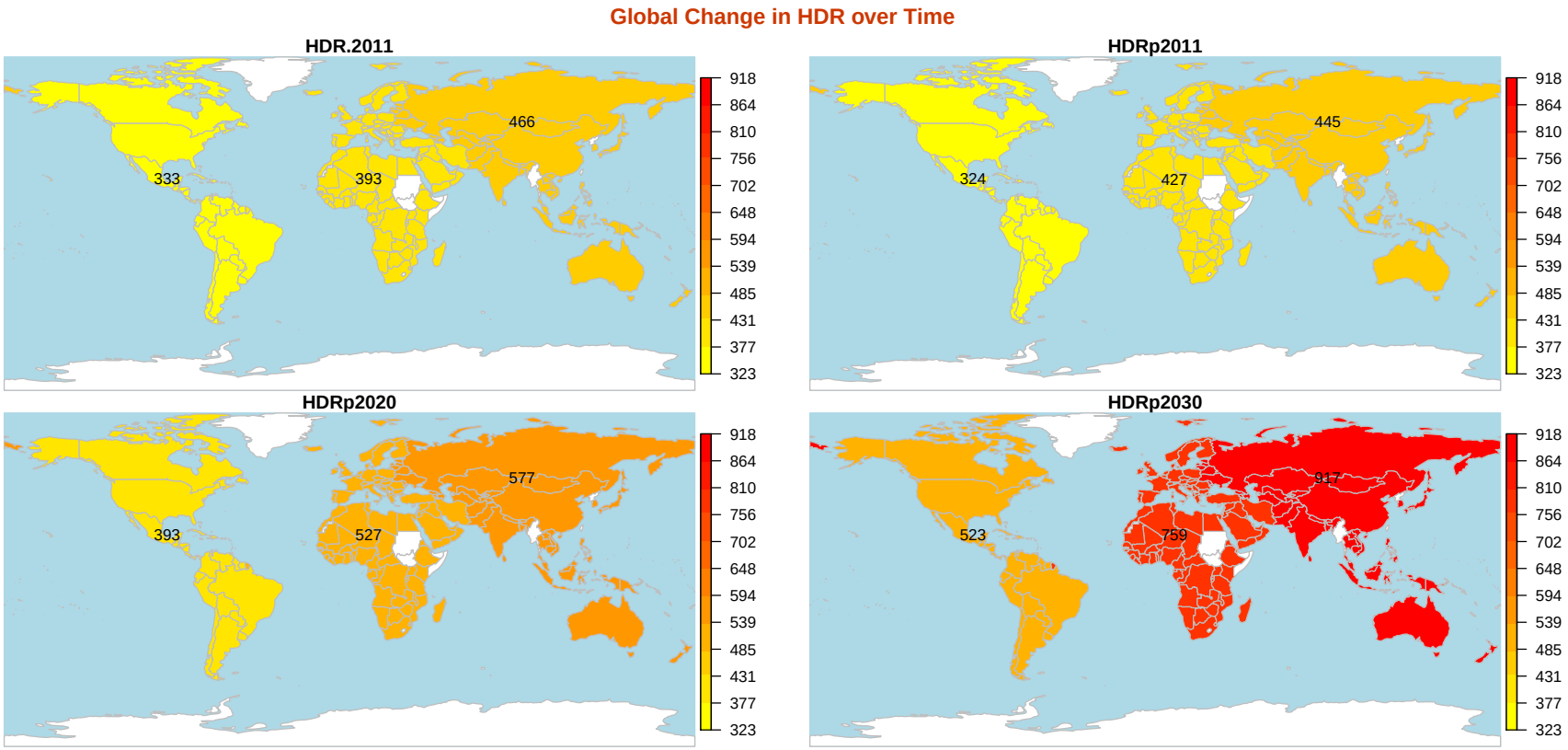

Figure 42: Global map for the distribution of actual and predicted HDR values for Three Regions (1. North and South America, 2. Europe, Africa and the Middle East, 3. Old USSR, Asia and Oceania).