PROCEEDINGS OF SPIE

SPIEDigitalLibrary.org/conference-proceedings-of-spie

Observed and expected changes in extreme precipitation frequency in Russia in the 20th-21st centuries

Aleshina, M., Cherenkova, E., Semenov, V., Bokuchava, D., Matveeva, T., et al.

M. A. Aleshina, E. A. Cherenkova, V. A. Semenov, D. D. Bokuchava, T. A. Matveeva, D. V. Turkov, "Observed and expected changes in extreme precipitation frequency in Russia in the 20th-21st centuries," Proc. SPIE 11208, 25th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 1120886 (18 December 2019); doi: 10.1117/12.2540921

SPIE.

Event: XXV International Symposium, Atmospheric and Ocean Optics, Atmospheric Physics, 2019, Novosibirsk, Russian Federation

Observed and expected changes in extreme precipitation frequency in Russia in the 20th-21st centuries

Aleshina M.A.*[a,b], Cherenkova E.A.[a,b], Semenov V.A.[a,b], Bokuchava D.D.[a,b], Matveeva T.A.[a,b], Turkov D.V.[a,b]

[a]Institute of Geography, Russian Academy of Sciences, Moscow, Russia; [b]A.M. Obukhov Institute of Atmospheric Physics of Russian Academy of Sciences, Moscow, Russia

ABSTRACT

Variations of the frequency of extreme daily precipitation events in winter and summer in the Russian Federation were studied for the 1961-2013 period using meteorological stations data. Future changes were estimated using data of the global climate models from CMIP5 model ensemble. In winter, there is a slight increase in the extreme precipitation frequency throughout Russia except for the Far East. By the end of the twenty-first century, models predict an overall strengthening of this trend. In summer, current changes are less significant and characterized by strong spatial heterogeneity. According to the CMIP5 models, the frequency of extreme precipitation will decrease in western and southern parts of Russia by the end of the 21st century and will increase in the northern and eastern regions.

Keywords: extreme precipitation, climate changes, climate models, meteorological station data, CMIP5.

1. INTRODUCTION

The IPCC AR5 report[1] provides evidence that observed climate changes can critically alter our planet. The water cycle characteristics are very important for our sustainable livelihood in the world. Averaged over the mid-latitude land areas of the Northern Hemisphere, precipitation has significantly increased since 1951. This is consistent with the expected response to a significant increase in atmospheric water vapor content as a result of the global warming [2,3].

According to the regional data analysis[4], the annual precipitation trend is positive over Russia (about 0.3 mm/month per 10 years). Furthermore, the annual amount of precipitation during the 1976-2010 period increased significantly faster than in 1936-2010. However, in summer there was a decrease in precipitation in European Russia and Eastern Siberia and an increase in precipitation in the other regions for the 1976-2010 period. It was also revealed that the duration of dry spells was increasing alone with the decrease of the extreme precipitation[5] in Russia. That means in some regions long periods without rain blends with cases of extreme precipitation. Also, an important factor is the combination of different types of precipitation (for instance, stratiform and convective). For example, the moderate increase in the total precipitation over Northern Eurasia over the last five decades is accompanied by much stronger growth of convective precipitation and the concurrent reduction of stratiform precipitation[6]. Such a redistribution of precipitation types may lead to negative impacts on ecosystems and population.

Increasing water holding capacity, stronger evaporation from the oceans, and, some other factors should result in an increase in extreme precipitation events. In fact, observations have shown a general increase in extreme precipitation in different regions of our planet since about 1950[7]. For example, in[8] authors have suggested the positive trends in days with extreme precipitation in winter and spring throughout most of Russia. In summer, a strong increase in extreme precipitation was observed in the Far East and in Central Russia. The previous study[9] showed that the frequency of extreme precipitation is projected to increase by the end of the 21st century for the Far East region in summer. It is important to note that trends in the frequency of extreme precipitation events are more uncertain as they related to dynamics of the atmosphere, in particular to frontal and convective processes. The aim of our study is to provide an overview of changes in extreme event indices in the CMIP5 models and observational data over Russia in 20th and 21st century.

2. DATA AND METHODS

Here we study the changes in the frequency of extreme precipitation in Russia since the middle of 20th to the end of 21st centuries. In order to detect changes in precipitation extremes, we compare the observational data and climate models. The days with daily precipitation exceeding the 95th percentile of daily precipitation distribution for a particular season

25th International Symposium On Atmospheric and Ocean Optics: Atmospheric Physics, edited by Gennadii G. Matvienko, Oleg A. Romanovskii, Proc. of SPIE Vol. 11208, 1120886
© 2019 SPIE · CCC code: 0277-786X/19/$21 · doi: 10.1117/12.2540921

are referred to as extreme precipitation days. By using that threshold we analyze changes in the frequency of extreme precipitation events (in days per season) for the 1991-2013 period (modern climate) compared to 1961-1990 (reference climate) and changes for 2071-2100 (future climate) relative to 1991-2013 period. This work provides results of comparison for winter and summer seasons.

The observed daily precipitation data were obtained from the dataset of the World Data Centre for Meteorology RIHMI-WDC (Obninsk, Russia, http://meteo.ru/). In the study, we analyzed the data from 524 meteorological stations.

We also examined the CMIP5[10] models data. We consider the following models: GFDL CM3, INM CM4, MPI-ESM-MR, MIROC5, HadGEM3-ES, data available from the Global Center for Environmental Data Analysis (http://data.ceda.ac.uk/badc/cmip5/metadata/pdf/models/). The scenario RCP 8.5 is considered that results in 8.5 W/m^2 radiation forcing by the end of the 21st century[11]. The model data were analysed in comparison with the observations to determine how well global climate models are able to simulate observed climatologies and trends. Historical runs were compared with observations for the period 1961-2013. Future projected changes were presented for the chosen extreme precipitation threshold for RCP8.5 emissions scenario.

2. RESULTS

As previously mentioned, in a warming climate, the global hydrological cycle is expected to intensify. According to climate models (see Figure 1) the amount of days with extreme precipitation have not changed significantly during the 20th century, neither for the European Russia nor Eastern Siberia. On the contrary, since the beginning of the 21st century, there has been an increase in this parameter for the two selected regions in winter (see Figure 1 a, c). In summer, there is no significant change detected (see Figure 1 b, d). It is also true that spatial patterns of precipitation changes are heterogeneous, with different regions showing opposing trends. That is why it is important to compare models with observational data and consider regional features of changes.

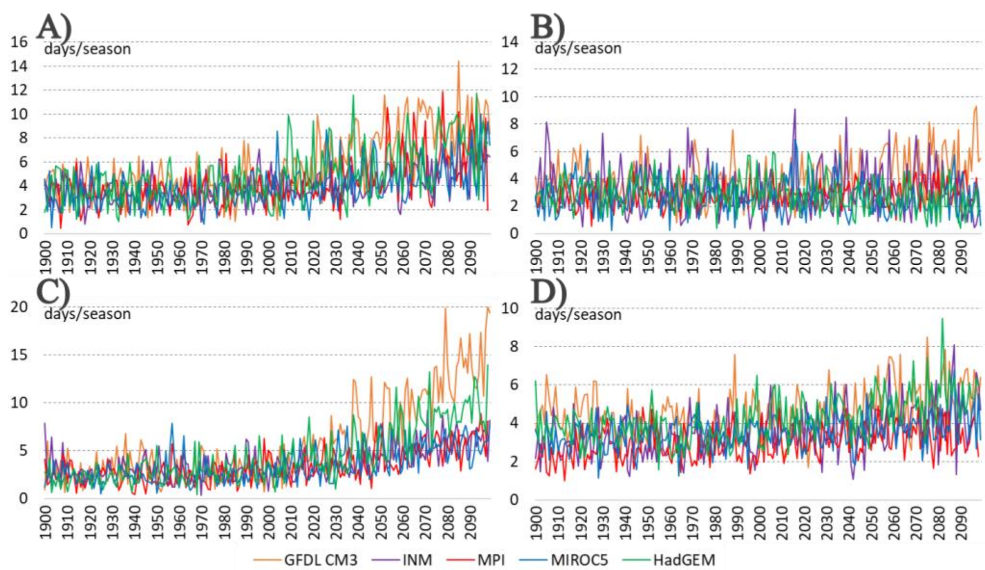

Figure 1. Number of days with extreme precipitations in winter (a, c) and summer (b, d) according to CMIP5 models (historical and RCP8.5 experiments) for the regions: a, b – European Russia (grid box 35-45° longitude and 52-60° latitude), and c, d – Eastern Siberia (grid box 115-135° longitude and 57-65° latitude).

Comparison of the meteorological station data and CMIP5 models for the winter season (see Figure 2) showed a predominant increase in the number of days with extreme precipitation (at rate 1-3 days/season), most pronounced in the European Russia, southern Siberia and the Far East. According to climate models, we find a relatively smaller increase in the number of days with extreme precipitation (1 - 2 days per season) in the Eastern Siberia and the European Russia. But the INM CM4 model shows the opposite changes, the decrease in extreme precipitation was 1-1.5 days per season.

At the same time, there is a decrease in extreme precipitation in the Far East and Chukotka based on meteorological stations data. However, climate models poorly reproduce that feature.

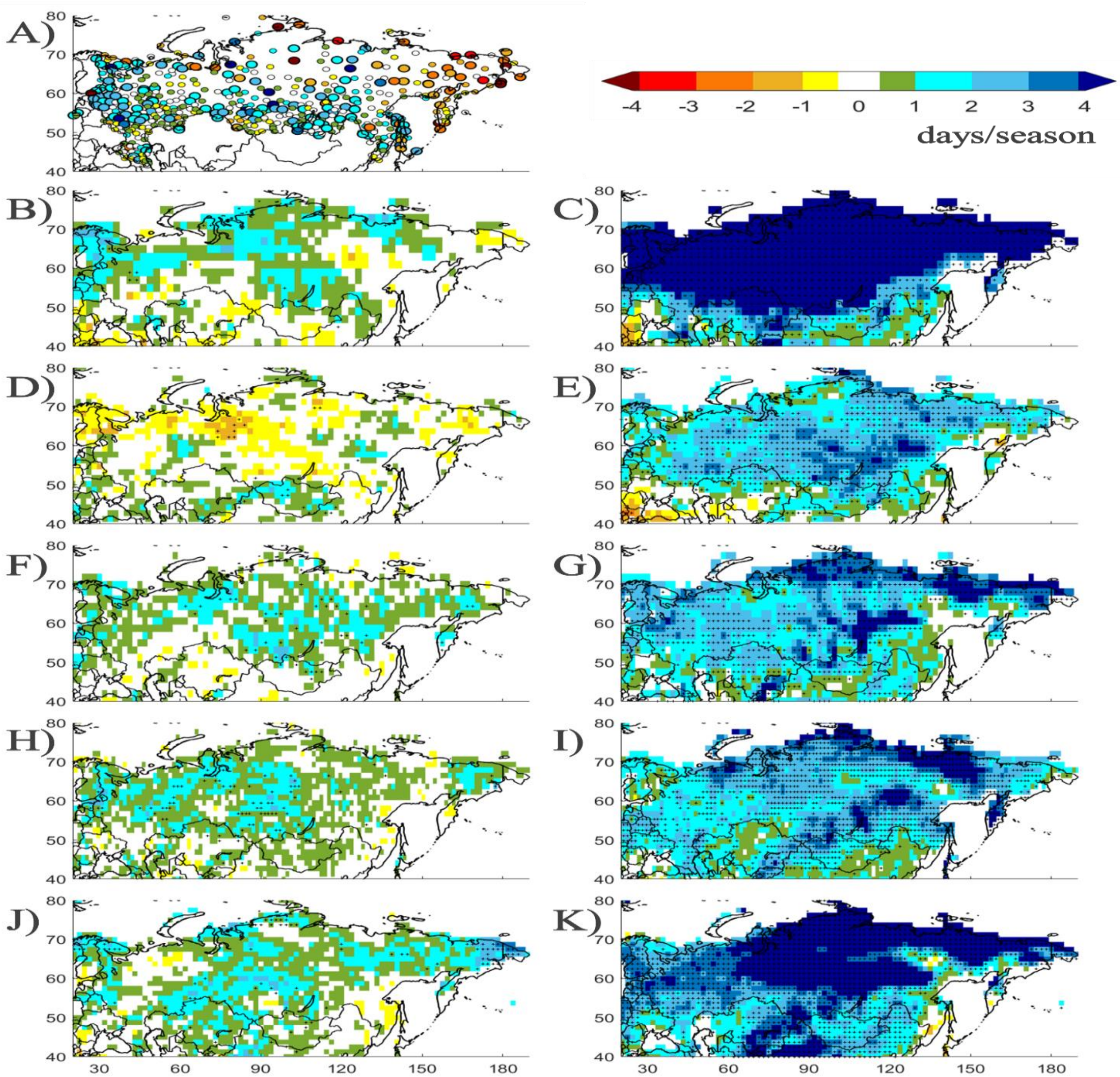

Figure 2. The difference in frequency of daily precipitation extremes (days per season) during winter in the 1991-2013 period in comparison to 1961-1990 (left figures) and 2071-2100 in comparison with 1991-2013 (right figures) according to weather stations data (a) and GFDL-CM3 (b, c), INM CM4 (d, e), MPI-ESM-MR (f, g), MIROC5 (h, i), HadGEM3-ES (j, k) models. Significant differences at 0.05 level are indicated by heavy black circles for meteorological station data and by black dots for models.

To the end of 21th century, a strong increase of days with extreme precipitation is predicted in all models by an average of 3 - 6 days per season, especially in the Eastern and Northern regions of Russia (see Figure 2c,e,g,i,k). The strongest increase of precipitation extremes was depicted in the GDFL-CM3 model. Here the number of days with extreme precipitation is projected to be more than doubled compared to the previous century (see Figure 2c).

In summer, changes have a smaller amplitude compared to the winter. Changes in precipitation patterns are diverse and statistically insignificant in most of the regions (see Figure 3a). There is a small number of stations with statistically significant positive changes (0.5-2 days per season) in the European Russia and eastern Siberia. Negative changes are noted on the Arctic coast, south part of European Russia, Chukotka peninsula and Southern Siberia.

As shown in Figure 3, the summer season in the 1991-2013 period in climate models is also characterized by weak changes in extreme precipitation characteristics. There is a growth of extreme events by on average of 0.5-1.5 days per season in Siberia and a slight decrease in European Russia.

The models do not reproduce the observed decrease in extreme precipitation on the Arctic coast and Chulotka (see Figure 3a). According to climate model projections, the number of days with extreme precipitation is expected to increase by the end of the 21st century in the Eastern part of the country and on the coastal regions of the Arctic seas (based on the GFDL model by more than 4 days per season). At the same time, there is a decrease in days with extreme precipitation (especially for the HadGEM model) simulated in the European part of Russia (see Figure 3k). The GFDL-CM3 shows the positive trend of extreme rains for the entire Russian territory.

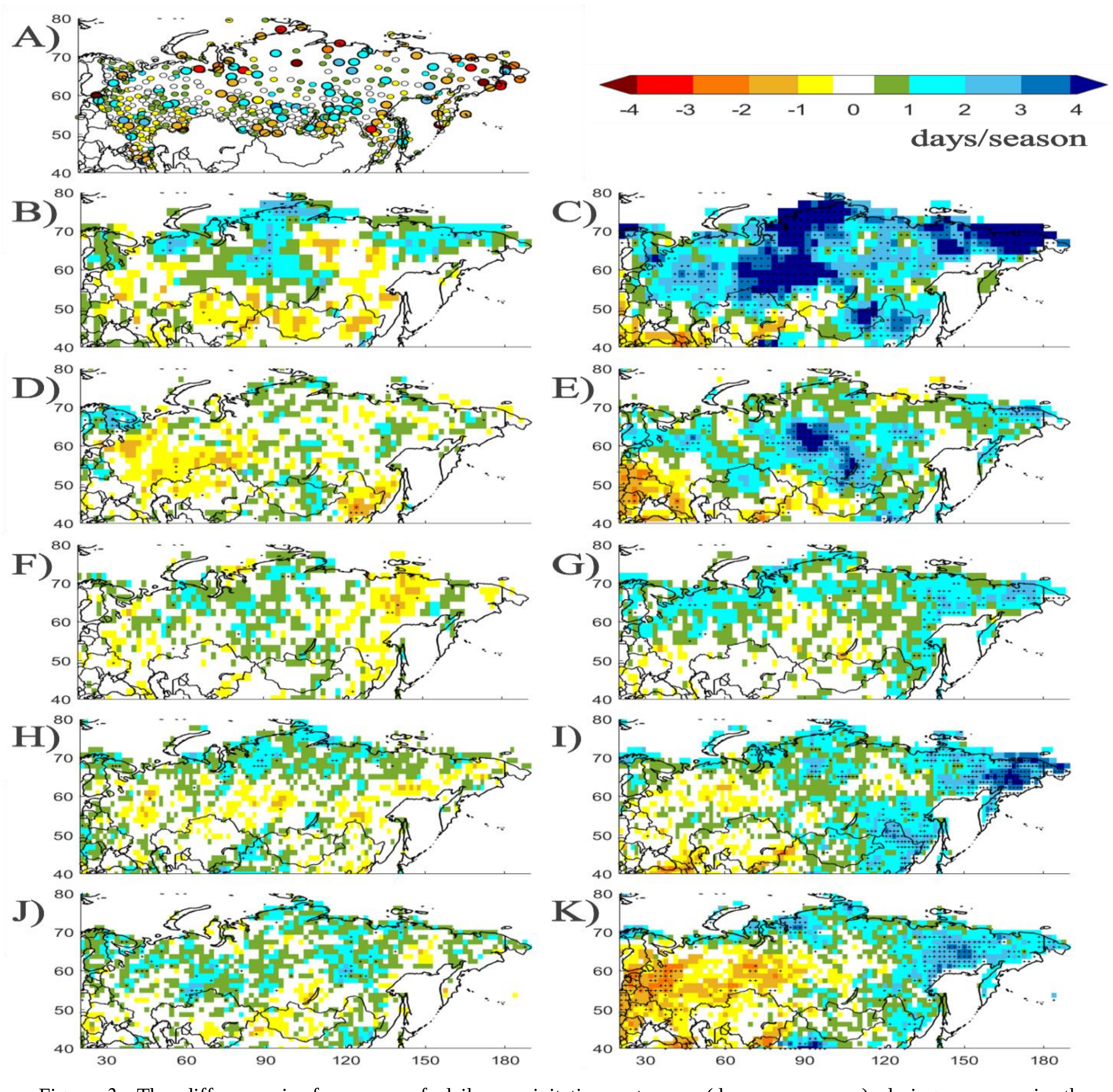

Figure 3. The difference in frequency of daily precipitation extremes (days per season) during summer in the 1991-2013 period in comparison to 1961-1990 (left figures) and 2071-2100 in comparison with 1991-2013 (right figures) according to weather stations data (a) and GFDL-CM3 (b, c), INM CM4 (d, e), MPI-ESM-MR (f, g), MIROC5 (h, i), HadGEM3-ES (j, k) models. Significant differences at 0.05 level are indicated by heavy black circles for meteorological station data and by black dots for models.

3. CONCLUSIONS

According to the conducted analysis of meteorological stations, there have been noticeable changes in extreme precipitation frequency throughout Russia since the middle of the 20th century. An increase in days with extreme precipitation was the overall feature of the winter season. The maximum changes in the modern climate occurred in the European part of Russia and southern Siberia. At the same time, there is a decrease in extreme precipitation on the Arctic coast. In summer there was an increase of extreme precipitation in the East part of the country and a slight decrease in the western regions.

The CMIP5 models perform well when comparing results with observations. The previous findings are consistent among the models, fit to the observed tendencies and stable for most of the regions. At the same time, climate models showed less amplitude of changes than meteorological station data for the modern climate. However, many regional assessments were similar at the qualitative level.

Climate projections for the rest of the 21st century show continued and associated with warming intensification of daily precipitation extremes, especially for wintertime. In winter, CMIP5 simulations project significant growth of the number of extreme precipitationover the eastern and northern regions of the country. For the summer season, models projected an increase in days with extreme precipitation in the eastern and northern regions and a decrease in European Russia. The GFDL-CM3 climate model showed the strongest changes for both seasons compared to other models by the end of the 21st century. In winter changes exceeds 5 days per season for the entire territory of Russia and more than 10 days/season in the northern Siberia. In summer the growth amounts to 3-6 days per season in Western and Northern Siberia.

aleshina@igras.ru

ACKNOWLEDGEMENTS

The study was supported by the Ministry of Science and Higher Education of the Russian Federation, agreement № 14.616.21.0082 (RFMEFI61617X0082).

REFERENCES

[1] Stocker, T, ed. Climate change 2013: the physical science basis: Working Group I contribution to the Fifth assessment report of the Intergovernmental Panel on Climate Change. Cambridge University Press, 2014.

[2] Min, S. K., Zhang, X., Zwiers, F. W., & Hegerl, G. C., "Human contribution to more-intense precipitation extremes," Nature, 470(7334), 378 (2001).

[3] Semenov, V.A., & Bengtsson, L. "Secular trends in daily precipitation characteristics: Greenhouse gas simulation with a coupled AOGCM," Climate Dynamics, 19(2), 123-140 (2002).

[4] Roshydromet second assessment report on climate change and its consequences in the Russian Federation, Moscow, 1008 (2014). [in Russian]

[5] Zolina, O., and Bulygina, O., "Current climatic variability of extreme precipitation in Russia," Fundamental and Applied Climatology, 1, 84-103 (2016).

[6] Chernokulsky, A., et al., "Observed changes in convective and stratiform precipitation over Northern Eurasia during the last decades." Environmental Research Letters (2019).

[7] Orlowsky, B., and Seneviratne, S., "Global changes in extreme events: regional and seasonal dimension," Climatic Change 110.3-4: 669-696 (2012).

[8] Zolotokrylin, A. and Cherenkova, E., "Seasonal changes in precipitation extremes in Russia for the last several decades and their impact on vital activities of the human population." Geography, environment, sustainability 10.4 (2018): 69-82.

[9] Cherenkova, E.A., Semenov, V.A., Babina, E. D., Aleshina, M. A., Bokuchava, D. D., "Modern and projected changes of extreme summer precipitation in the Far East of Russia," Proc. SPIE 10833, 24th International Symposium on Atmospheric and Ocean Optics: Atmospheric Physics, 108337A (2018).

[10] Taylor, K. E., Stouffer, R.J., Meehl, G.A., "An overview of CMIP5 and the experiment design." Bulletin of the American Meteorological Society 93.4, 485-498 (2012).

[11] Rogelj, J., Meinshausen, M., Knutti, R., "Global warming under old and new scenarios using IPCC climate sensitivity range estimates", Nature Climate Change 2, 248–253 (2012).