CHIPS
Climate Change Impacts and Policies in Heterogeneous Societies

WP 2: Novel damage functions, impact channels and spatial heterogeneity

M2.1: Decision on hazard types to be included in the analysis

JPI Climate AXIS

FEBRUARY 2020

WP 2: Novel damage functions, impact channels and spatial heterogeneity

M2.1: Decision on hazard types to be included in the analysis

Thomas Vogt & Christian Otto (PIK)

As part of CHIPS work package 2 (WP 2), biophysical impact indicators (e.g. flood depth, wind speed, crop yields) will be combined with refined socioeconomic data sources (spatially-explicit population and asset data) and observed damage data to i) translate local hazard characteristics into damages and ii) project an ensemble of multi-model future damages for different hazards. As outlined in this milestone report, we decided to include the following hazard types in the analysis: river floods, crop failure from droughts, labor productivity, and tropical cyclones.

Rationale

River floods and tropical cyclones are among the costliest categories of extreme weather events, causing USD 37.1 bn and USD 51.9 bn (2018 values) in direct annual damage within the last decade on average according to the NatCatSERVICE Database (MunichRE 2020). While river floods affect almost all inhabited areas of the globe, they are highly relevant for the situation in Europe where they are among the most important natural hazards in terms of economic damage (European Environment Agency 2017). Recent changes in European river flood risk can already be attributed to climate change impacts (Blöschl et al. 2019). On a regional level, crop failures from droughts are expected to increase significantly under climate change; the most severe increase in drought risk is expected for the Amazon, the Mediterranean, and South Africa. In CHIPS, distributional effects of droughts in Spain were identified as a case study for work package 3 (WP 3). Tropical cyclones will be relevant for the global integrated assessment models in WP 4.

As principal transmission channels through which climate extremes impact on socioeconomic development in the long-run, we account for losses of capital stocks and reduced labor productivity. With this choice of hazard types, we will be able to build on recent efforts for damage estimates in the area of river flood damages (Huinzinga et al. 2017, Dottori et al. 2018, Zhao et al. 2017, Yamazaki et al. 2011), coastal flood damages (Hinkel et al. 2014, Vousdoukas et al. 2018), while for tropical cyclone damages (Mendelsohn et al. 2012, Geiger et al. 2016, Geiger et al. 2018), crop failures and labor productivity losses no systematic damage quantification exists on a global level to date. CHIPS will build on these previous efforts to build hazard-specific, event-based economic damage functions.

Input data

CHIPS will build on the process-based impact simulations within the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP, www.isimip.org), coordinated at PIK. ISIMIP provides cross-sectorally consistent climate, sea level (Mengel et al. 2016) and socioeconomic forcing data (Geiger 2018) that are used to drive harmonized multi-model impact-model simulations (e.g. Frieler et al. 2017). In cooperation with more than 100 modeling teams from different disciplines, ISIMIP defines a common modelling protocol for climate-impact science. Within CHIPS, we use historical impact simulations generated within ISIMIP2a/3a by driving the impact models with observed weather data as well as future projections generated within ISIMIP2b/3b for a high-end, business-as-usual and a strong mitigation greenhouse gas emission scenario (Relative Concentration Pathways 8.5, 6.0 and 2.6) (Frieler et al. 2017). In this way, we profit from the latest impact model improvements as well as new developments regarding the bias-correction method applied to the ISIMIP3 climate forcing data (Lange 2019) and the detailed translation of Shared Socioeconomic Pathways (SSP, O'Neill et al. 2014) into impact model forcing data such as agricultural management changes, water management, and land use patterns accounting for different levels of bio-energy demand.

Methods and output data

Based on biophysical impact simulations, we derive indicators such as areas affected by floods or extreme winds for the historical period and a high-end, a business-as-usual and a low future emission scenario. For model evaluation, we compare simulated biophysical impact indicators to available observational data. The historical biophysical hazard indicators are combined with socioeconomic information to derive damage predictors such as "assets affected by flooding exceeding a certain depth", "assets affected by wind of hurricane strength" or "losses in agricultural production". By regression approaches, we then test to what degree these predictors can explain the variations in reported damages induced by extreme weather events. We use the calibrated functional relationships (damage functions) to generate future projections of damages accounting for climate change and socioeconomic developments along the SSPs. Further, in a literature study, we identify promising approaches to estimate the dependence of direct disaster damages upon income, e.g. by following the rapidly developing research area on social vulnerability (Otto et al. 2017, Rufat et al. 2015). To date, methods to study the inequalities of impacts between poor people and richer parts of the populations have been only developed for specific cast study regions (Hallegate & Rozenberg 2017). In CHIPS, we will assess the extendibility of these methods to the global level.

Links to other work packages in CHIPS

Finally, these event-based damage functions are transformed into income-specific temperature-based damage functions. As they express economic damages (e.g., asset losses, losses in labor productivity) as functions of global mean temperature, they can be directly employed in Integrated Assessment Models of Climate and Economy (IAMs) to assess the combined impacts of extreme weather events and mitigation measures on socioeconomic development pathways accounting for in-between as well as within-country inequalities (WP 4).

Detailed information on hazard types

River floods. For damages due to fluvial floods, we rely on observed climate data driving hydrological and river routing models in ISIMIP2a/3a (Gosling et al. 2019). ISIMIP provides four separate historical (atmospheric) climate data sets to drive 12 global grid-based hydrological models (GHMs). For this ensemble of 46 climate data/GHM combinations, we follow Hirabayashi et al. (2013) and Willner et al. (2018) to derive flood depth and flooded areas. This is done by driving the river routing model CaMa-

Flood (Yamazaki et al. 2011) with the runoff of the GHMs, using high resolution topographic data (Yamazaki et al. 2011) combined with current flood protection levels from the FLOPROS database (Scussolini et al. 2016). This has been shown to better represent observed river discharge compared to direct GHM output (Zhao et al. 2017). First, superimposing flooded areas with gridded population data provided by the HYDE project (Goldewijk et al. 2017) enables us to estimate the number of flood-affected people. Second, by downscaling national data on physical capital stocks from the Penn World Tables v9.2 (Feenstra et al. 2015) and accounting for state-of-the-art continent specific damage functions (Huizinga et al. 2017), we obtain simulated direct losses to the capital stock. These loss estimates can be further refined by assuming that, on the level of world regions, the vulnerability to flood events changes with per-capita GDP. Here, the vulnerability is defined as the ratio of observed damages as reported in the NatCatSERVICE database (Munich RE 2020) and simulated losses (Tanoue et al. 2016).

Agricultural droughts. The ISIMIP2a/3a (historical period) and ISIMIP2b/3b (future period) modeling rounds comprise global gridded simulations of potential yields for the four main staple crops (maize, rice, soybean, and wheat) from multiple process-based global crop models. These simulations account for different management options such as irrigation and fertilizer use (Frieler et al. 2017). Since ISIMIP aims for cross-sectoral consistency of impacts, these simulations account, for instance, for water availability constraints. Previous works show that these process-based models can well describe the yield response to heatwaves and drought conditions (Schauberger et al. 2017).
We overlay these yield simulations with historical production patterns to derive globally consistent annual yield losses for the historical period (1970-2016). A gridded (0.5 degree resolution) binary drought indicator is defined by assuming that a grid cell is drought affected if the yield in this cell falls short of the 2.5th percentile of the multi-annual average. We then derive an economic damage function by regressing national agricultural drought losses as reported by NatCatSERVICE or EM-DAT (EM-DAT 2020) using this drought indicator as predictor. The drought indicator will also feed into the case study on droughts planned in WP 3.

Labor productivity. For the first time, labor productivity effects will be determined within ISIMIP based on exposure response functions from the literature as well as a new, empirically derived response function based on a large global data set. The empirical study finds different optimal temperatures for low and high exposure sectors. Using climate input data like temperature and humidity, projections for labor productivity losses will be calculated and used in integrated assessment.

Tropical cyclones. Tropical cyclone (TC) impacts are an outstanding example for the harmful interference of ongoing global warming and socioeconomic development (Estrada et al. 2015, Knutson et al. 2019a). While under global warming stronger and more frequent TCs of highest category are expected to occur (Knutson et al. 2019b), TC related co-hazards such as flooding through extreme precipitation (Knutson et al. 2015), more stalling events (Hall & Kossin 2019), as well as stronger surges due to sea level rise (Woodruff et al. 2013) are expected to intensify. At the same time, we observe population growth in coastal urban areas (Neumann et al. 2015). In combination, these trends will result in more severe TC impacts, in particular, when considering that adaptation to extreme winds and precipitation with very limited warning time is notoriously difficult. However, studies on how climate change impacts on TC are often focused on projected changes in physical TC properties only, e.g. on the TC power dissipation index (Sobel et al. 2016), or on rather general (Knutson et al. 2019b) or country-specific assessments (Jisan et al. 2018).

We will conduct a globally consistent basin specific assessment of TC induced losses for both observed (Knapp et al. 2010) and potential future realizations (Emanuel 2013) of storm tracks accounting for global mean sea level rise (Mengel et al. 2016). In addition to impacts from severe winds, we introduce information about coastal flooding as a second predictor in the newly developed damage function for tropical cyclones going beyond purely wind field based approaches (Geiger et al. 2016). This enables us to take into account sea level rise as one main climate change driver of TC losses. The input storm tracks will be combined with a wind field model (Holland et al. 2010) and the state-of-the-art and computationally efficient clawpack model (Mandli et al. 2016), which calculates flood depth, extent, and duration accounting for flow speeds according to shallow water equations. Basin specific multivariate empirical damage functions are then constructed by regressing observed economic damages in the international disaster databases NatCatSERVICE (Munich RE 2020) and EM-DAT (EM-DAT 2020) with wind and flood depth as biophysical drivers. Where possible, we calibrate the damage function with events for which disentangled wind and surge damages are available, e.g., from the flood-insurance claims for coastal regions as published by the Federal Emergency Management Agency (FEMA 2020).

References

Blöschl, G. et al. (2019): Changing climate both increases and decreases European river floods. Nature, 573(7772): 108–111.

Dottori, F., Szewczyk, W., Ciscar, J.-C., Zhao, F., Alfieri, L, Hirabayashi, Y., Bianchi, A., Mongelli, I., Frieler, K., Betts, R.A., Feyen, L. (2018): Increased human and economic losses from river flooding with anthropogenic warming. Nature Climate Change 8(9): 781-786.

EM-DAT (2020): The Emergency Events Database. Université catholique de Louvain (UCL), CRED, D. Guha-Sapir. www.emdat.be

Emanuel, K.A. (2013): Downscaling CMIP5 climate models shows increased tropical cyclone activity over the 21st century. Proceedings of the National Academy of Sciences 110(30): 12219–12224.

Estrada, F., Botzen, W. J. W., Tol, R. S. J. (2015): Economic losses from US hurricanes consistent with an influence from climate change. Nature Geoscience, 8(11): 880–884.

European Environment Agency (2017): Climate change, impacts and vulnerability in Europe 2016: An indicator-based report.

Feenstra, R.C., Inklaar, R., Timmer, M.P. (2015): The Next Generation of the Penn World Table. American Economic Review 105(10): 3150–3182.

FEMA (2020): FEMA.gov: Policy & Claim Statistics for Flood Insurance. https://www.fema.gov/policy-claim-statistics-flood-insurance

Frieler, K. et al. (2017): Assessing the impacts of 1.5 °C global warming – simulation protocol of the Inter-Sectoral Impact Model Intercomparison Project (ISIMIP2b). Geoscientific Model Development, 10(12): 4321–4345.

Geiger, T. (2018): Continuous national gross domestic product (GDP) time series for 195 countries: Past observations (1850–2005) harmonized with future projections according to the Shared Socio-economic Pathways (2006–2100). Earth System Science Data, 10(2): 847–856.

Geiger, T., Frieler, K., Bresch, D. N. (2018): A global historical data set of tropical cyclone exposure (TCE-DAT). Earth System Science Data, 10(1): 185–194.

Goldewijk, K.K., Beusen, A., Doelman, J., Stehfest, E. (2017): Anthropogenic land use estimates for the Holocene - HYDE 3.2. Earth System Science Data 9(2): 927–953.

Gosling, S. et al. (2019): ISIMIP2a Simulation Data from Water (global) Sector (V. 1.1). GFZ Data Services. http://dataservices.gfz-potsdam.de/pik/showshort.php?id=escidoc:3928901

Hall, T. M., Kossin, J. P. (2019): Hurricane stalling along the North American coast and implications for rainfall. Npj Climate and Atmospheric Science, 2(1): 1–9.

Hallegatte, S., Rozenberg, J. (2017): Climate change through a poverty lens. Nature Climate Change 7(4): 250–256.

Hinkel, J., Lincke, D., Vafeidis, A.T., Perrette, M., Nicholls, R.J., Tol, R.S.J., Marzeion, B., Fettweis, X., Ionescu, C., Levermann, A. (2014): Coastal flood damages and adaptation costs under 21st century sea-level rise. PNAS 111(9): 3292-3297.

Hirabayashi, Y., Mahendran, R., Koirala, S., Konoshima, L., Yamazaki, D., Watanabe, S., Kim, H., Kanae, S. (2013): Global flood risk under climate change. Nature Climate Change, 3(9): 816–821.

Holland, G. J., Belanger, J. I., Fritz, A. (2010): A Revised Model for Radial Profiles of Hurricane Winds. Monthly Weather Review, 138(12): 4393–4401.

Huizinga, J., de Moel, H., Szewczyk, W. (2017): Global flood depth-damage functions. JRC Technical Reports, EUR 28552 EN. Joint Research Centre: European Commission.

Jisan, M. A., Bao, S., Pietrafesa, L. J. (2018): Ensemble projection of the sea level rise impact on storm surge and inundation at the coast of Bangladesh. Natural Hazards and Earth System Sciences, 18(1): 351–364.

Knapp, K. R., Kruk, M. C., Levinson, D. H., Diamond, H. J., Neumann, C. J. (2010): The International Best Track Archive for Climate Stewardship (IBTrACS). Bulletin of the American Meteorological Society, 91(3): 363–376.

Knutson, T. R., Sirutis, J. J., Zhao, M., Tuleya, R. E., Bender, M., Vecchi, G. A., Villarini, G., Chavas, D. (2015): Global Projections of Intense Tropical Cyclone Activity for the Late Twenty-First Century from Dynamical Downscaling of CMIP5/RCP4.5 Scenarios. Journal of Climate, 28(18): 7203–7224.

Knutson, T., Camargo, S. J., Chan, J. C. L., Emanuel, K., Ho, C.-H., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K., Wu, L. (2019): Tropical Cyclones and Climate Change Assessment: Part I: Detection and Attribution. Bulletin of the American Meteorological Society, 100(10): 1987–2007.

Knutson, T., Camargo, S. J., Chan, J. C. L., Emanuel, K., Ho, C.-H., Kossin, J., Mohapatra, M., Satoh, M., Sugi, M., Walsh, K., Wu, L. (2019): Tropical Cyclones and Climate Change Assessment: Part II. Projected Response to Anthropogenic Warming. Bulletin of the American Meteorological Society. In Print.

Lange, S. (2019): Trend-Preserving Bias Adjustment and Statistical Downscaling - Enhancement of the ISIMIP Approach. Earth System Dynamics Discussions: Submitted.

Mandli, K. T., Ahmadia, A. J., Berger, M., Calhoun, D., George, D. L., Hadjimichael, Y., Ketcheson, D. I., Lemoine, G. I., LeVeque, R. J. (2016): Clawpack: Building an open source ecosystem for solving hyperbolic PDEs. PeerJ Computer Science, 2: e68.

Mendelsohn, R., Emanuel, K., Chonabayashi, S., Bakkensen, L. (2012): The impact of climate change on global tropical cyclone damage. Nature Climate Change 2: 205-209.

Mengel, M., Levermann, A., Frieler, K., Robinson, A., Marzeion, B., Winkelmann, R. (2016): Future sea level rise constrained by observations and long-term commitment. Proceedings of the National Academy of Sciences, 113(10): 2597–2602.

Munich RE (2020): NatCatSERVICE - Natural catastrophe know-how for risk management and research. Retrieved from https://natcatservice.munichre.com/

Neumann, B., Vafeidis, A. T., Zimmermann, J., Nicholls, R. J. (2015): Future Coastal Population Growth and Exposure to Sea-Level Rise and Coastal Flooding—A Global Assessment. PLOS ONE, 10(3): e0118571.

O'Neill, B. C., Kriegler, E., Riahi, K., Ebi, K. L., Hallegatte, S., Carter, T. R., Mathur, R., van Vuuren, D. P. (2014): A new scenario framework for climate change research: The concept of shared socioeconomic pathways. Climatic Change, 122(3): 387–400.

Otto, I.M., Reckien, D., Reyer, C.P.O., Marcus, R., Le Masson, V., Jones, L., Norton, A., Serdeczny, O. (2017): Social vulnerability to climate change: a review of concepts and evidence. Regional Environmental Change 17(6): 1651–1662.

Rufat, S., Tate, E., Burton, C.G., Maroof, A.S. (2015): Social vulnerability to floods: Review of case studies and implications for measurement. International Journal of Disaster Risk Reduction 14: 470–486.

Schauberger, B., Archontoulis, S., Arneth, A., Balkovic, J., Ciais, P., Deryng, D., Elliott, J., Folberth, C., Khabarov, N., Müller, C., Pugh, T. A. M., Rolinski, S., Schaphoff, S., Schmid, E., Wang, X., Schlenker, W., Frieler, K. (2017): Consistent negative response of US crops to high temperatures in observations and crop models. Nature Communications, 8(1): 1–9.

Scussolini, P., Aerts, J. C. J. H., Jongman, B., Bouwer, L. M., Winsemius, H. C., De Moel, H., Ward, P. J. (2016): FLOPROS: an evolving global database of flood protection standards. Natural Hazards and Earth System Sciences, 16(5): 1049–1061.

Sobel, A. H., Camargo, S. J., Hall, T. M., Lee, C.-Y., Tippett, M. K., Wing, A. A. (2016): Human influence on tropical cyclone intensity. Science, 353(6296): 242–246.

Tanoue, M., Hirabayashi, Y., Ikeuchi, H. (2016): Global-scale river flood vulnerability in the last 50 years. Scientific Reports 6(1): 1–9.

Vousdoukas, M.I., Mentaschi, L., Voukouvalas, E., Bianchi, A., Dottori, F., Feyen, L. (2018): Climatic and socioeconomic controls of future coastal flood risk in Europe. Nature Climate Change 8: 776–780.

Willner, S. N., Levermann, A., Zhao, F., Frieler, K. (2018): Adaptation required to preserve future high-end river flood risk at present levels. Science Advances, 4(1): 1–9.

Woodruff, J. D., Irish, J. L., Camargo, S. J. (2013): Coastal flooding by tropical cyclones and sea-level rise. Nature, 504(7478): 44–52.

Yamazaki, D., Kanae, S., Kim, H., Oki, T. (2011): A physically based description of floodplain inundation dynamics in a global river routing model. Water Resources Research, 47(4).

Zhao, F. et al. (2017): The critical role of the routing scheme in simulating peak river discharge in global hydrological models. Environmental Research Letters, 12(7): 075003.

Acknowledgement

The project CHIPS is part of AXIS, an ERA-NET initiated by JPI Climate, and funded by FORMAS (SE), DLR/BMBF (DE, Grant No. 01LS1904A), AEI (ES) and ANR (FR) with co-funding by the European Union (Grant No. 776608).