

Projected Hydroclimate Changes Driven by Carbon Dioxide Trends and Vegetation Modeling in CMIP6

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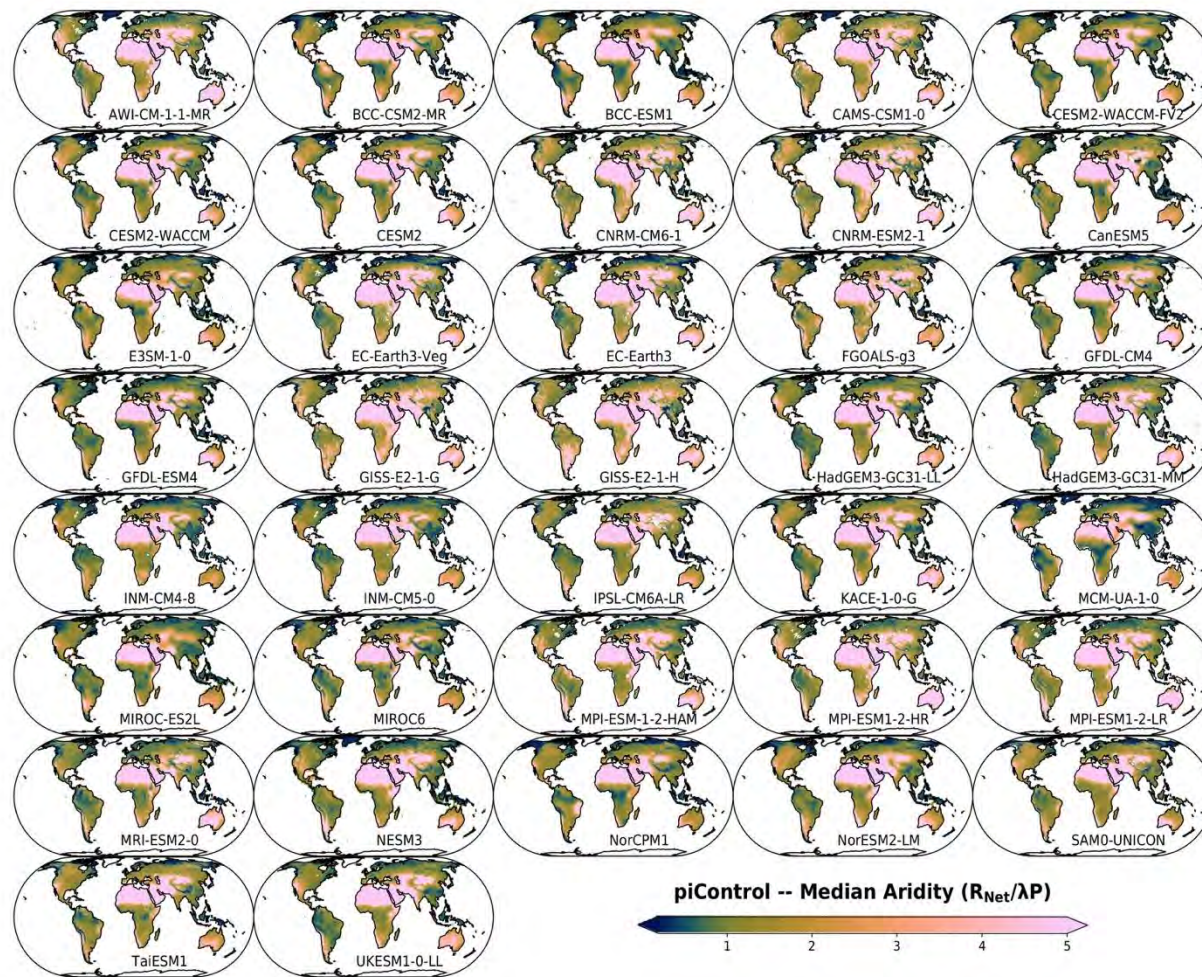
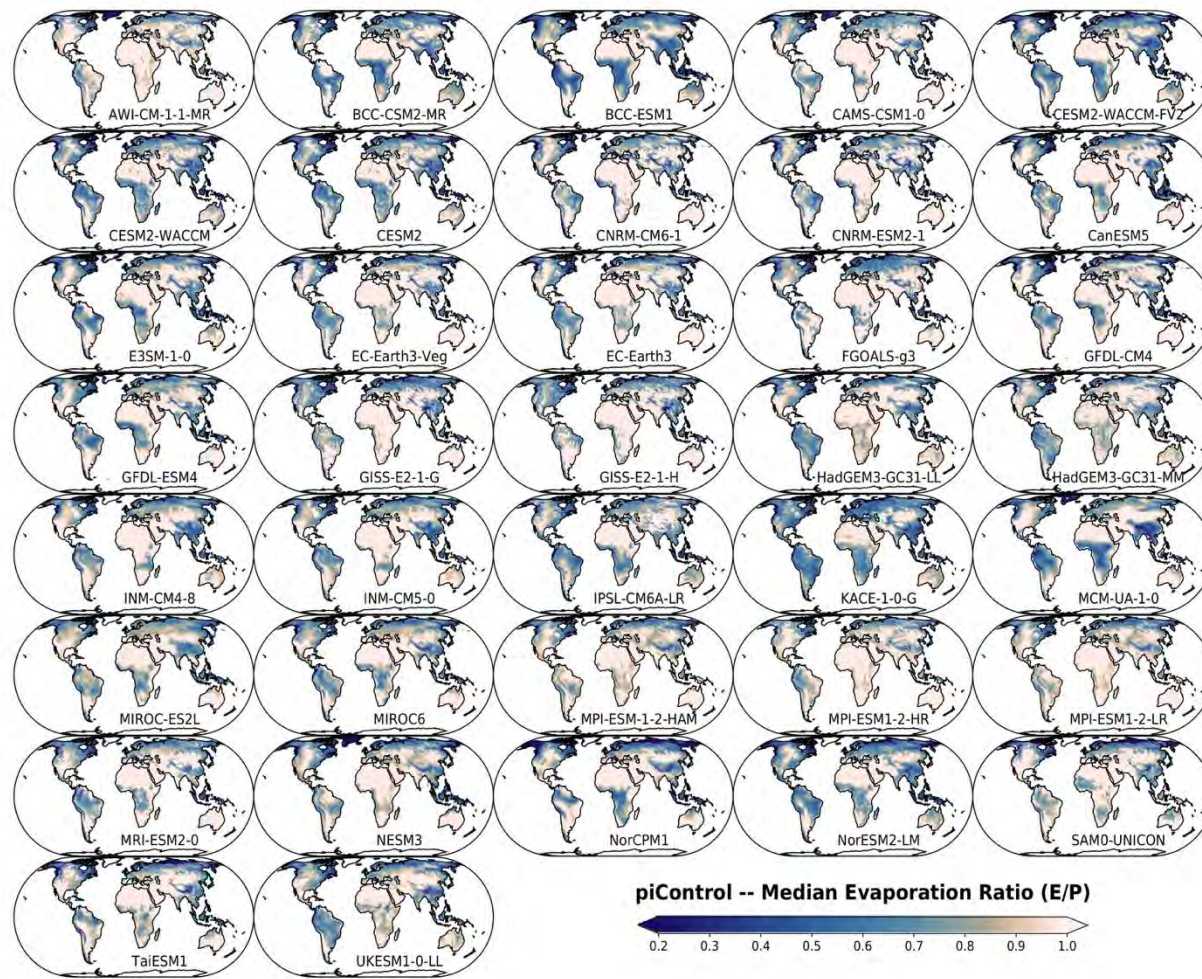


Figure S1. Time-median aridity values from the piControl simulation of each considered CMIP6 model.



23 **Figure S2.** As in Figure S1 for E ratio.

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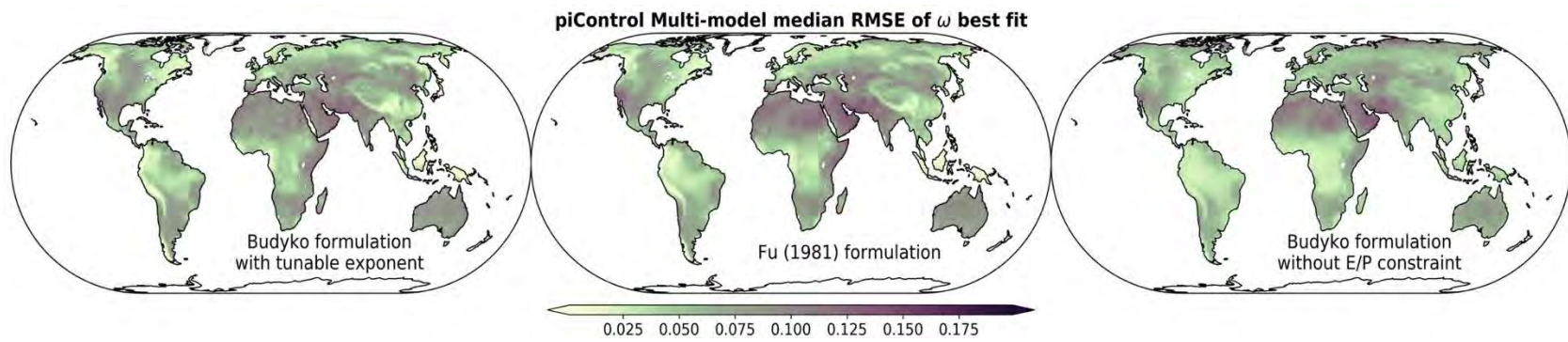


Figure S3. Root mean square error (RMSE) of the best fit Budyko curve of the indicated formulation through all yearly points in Budyko space (E/P versus $R_{net}/\lambda P$).

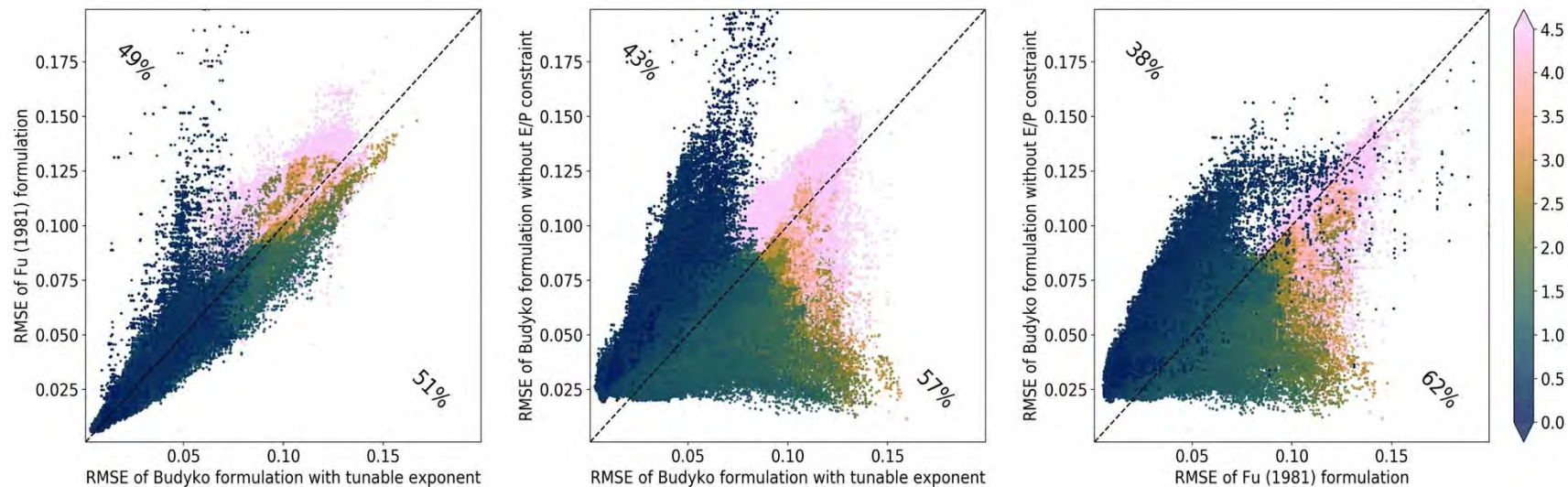


Figure S4. Scatter of multi-model median of RMSE of the optimal fit of the indicated Budyko formulation to the annual values of aridity and E ratio in the piControl experiment. Each point is a grid cell on the high-resolution interpolated grid. The percentages show the fraction of points on each side of the $x = y$ line. Coloring shows the multi-model median aridity calculated from each model's time-median at each grid cell.

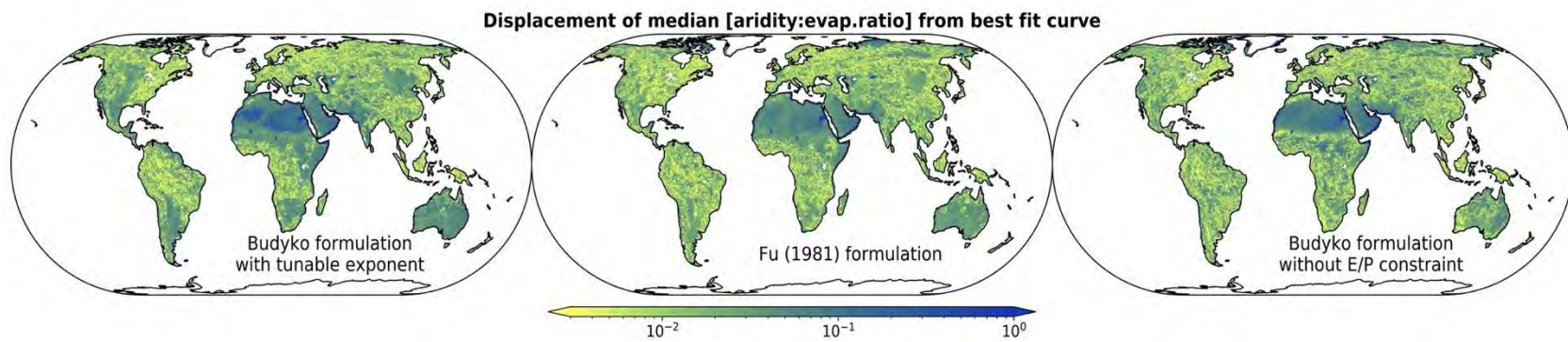


Figure S5. Displacement of the point in Budyko space representing the multi-model medians of aridity and E ratio from the nearest point on the best fit Budyko curve using the formulation indicated in each panel.

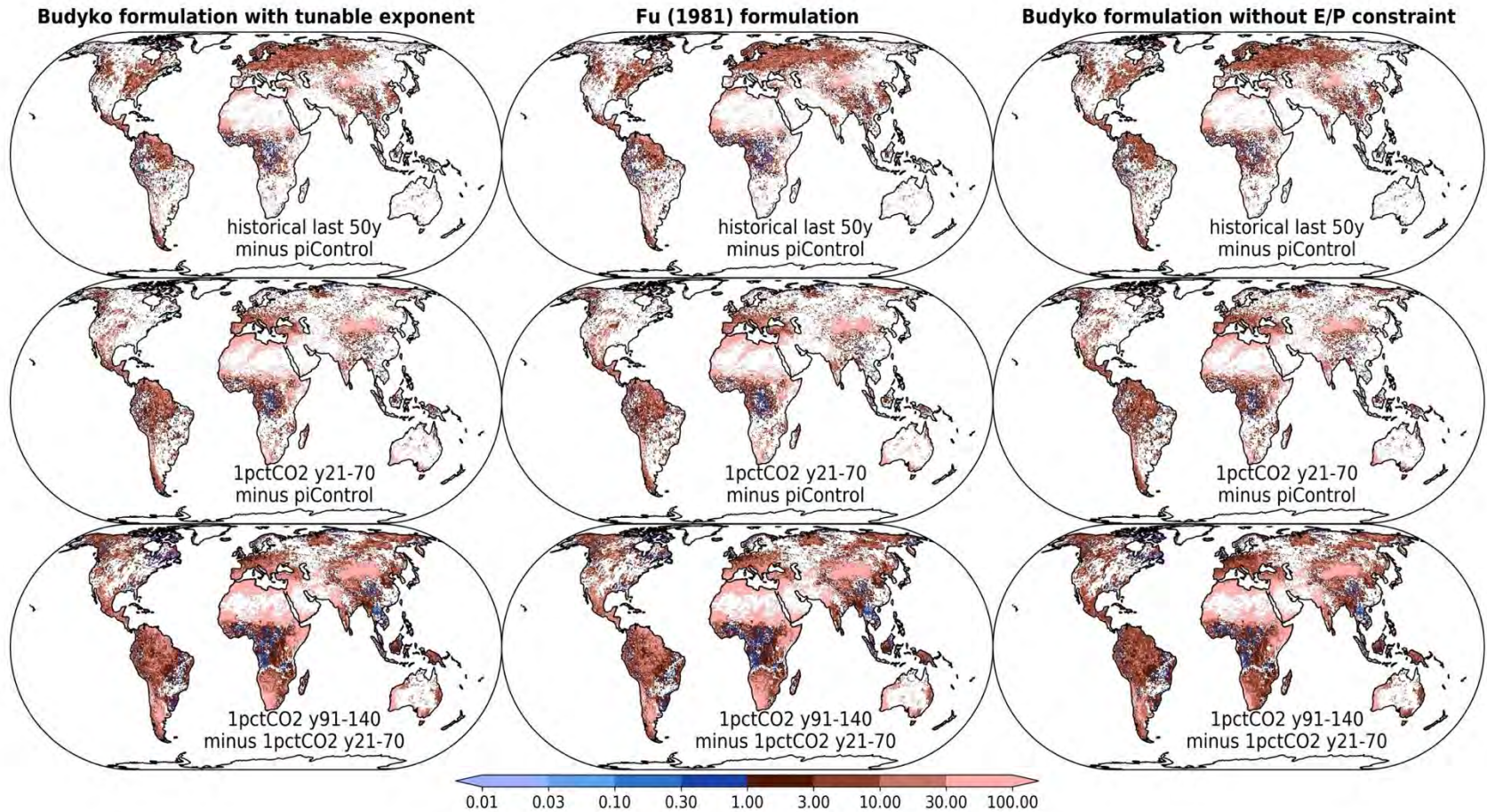


Figure S6. As in Figure 8 for the ratio of change parallel to the Budyko curve to change perpendicular to the Budyko curve.

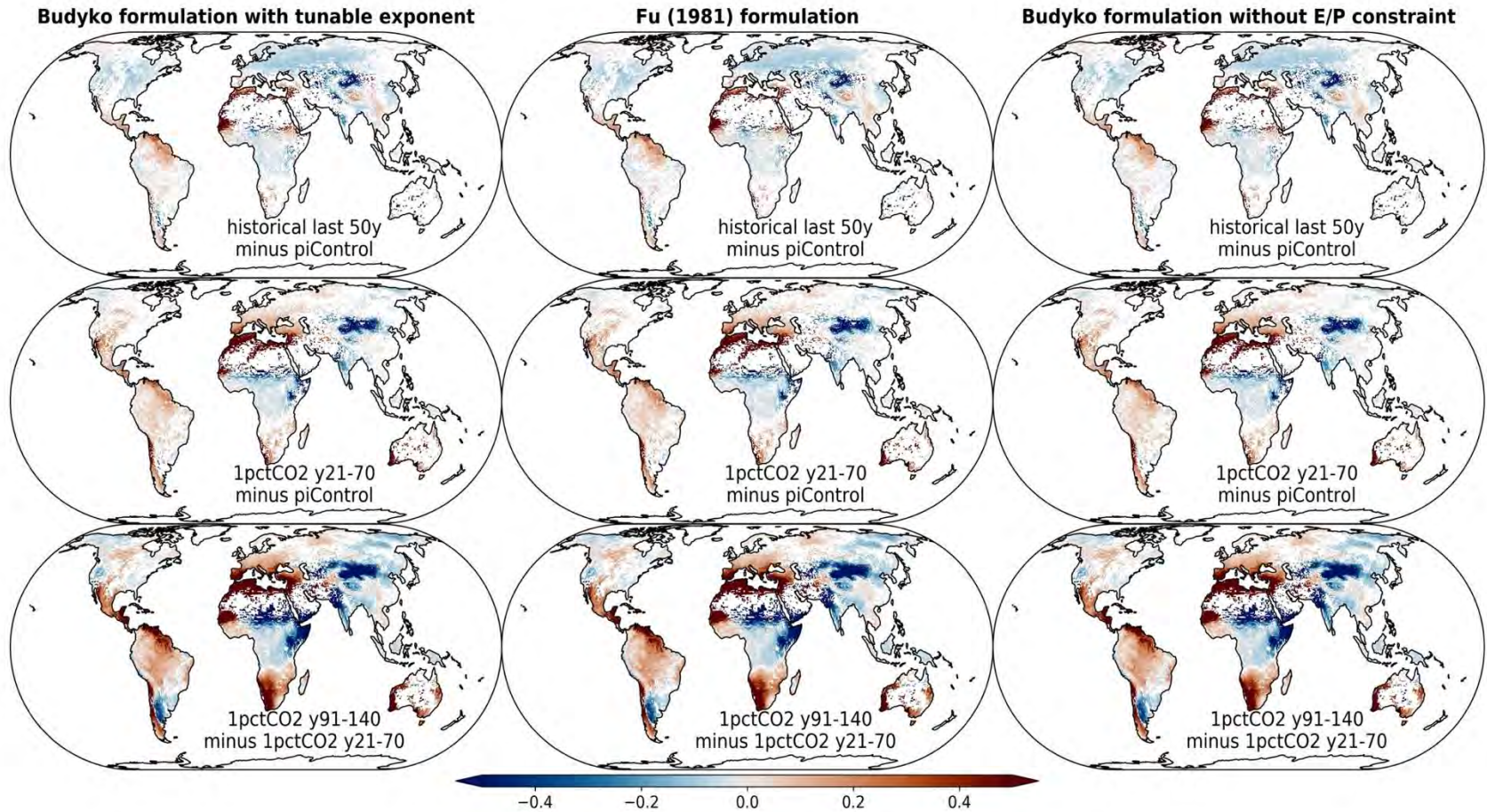


Figure S7. As in Figure S6 for the component parallel to the Budyko curve (the numerator in Figure S6).

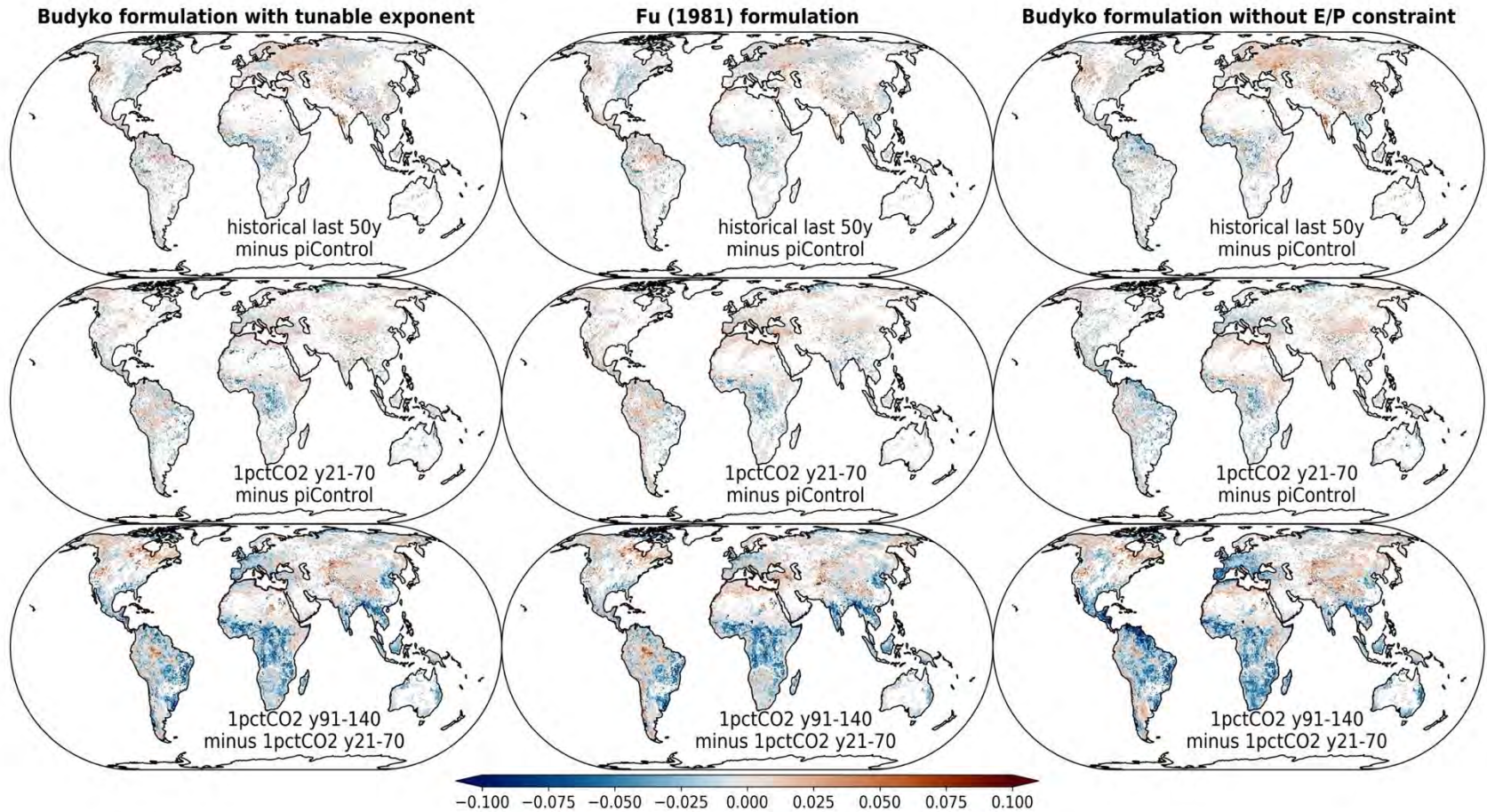


Figure S8. As in Figure S6 for the component perpendicular to the Budyko curve (the denominator in Figure S6).

53 **Table S1:** CMIP model full citations and whether the models predict vegetation phenology (Phen) or include a fully dynamic vegetation
54 model (DVM). For some models we were unable to verify vegetation model capabilities from the literature.

CMIP Label	DVM	Phen	Full Citation
AWI-CM-1-1-MR	No	Yes	Semmler, Tido; Danilov, Sergey; Rackow, Thomas; Sidorenko, Dmitry; Barbi, Dirk; Hegewald, Jan; Sein, Dmitri; Wang, Qiang; Jung, Thomas (2018). AWI AWI-CM1.1MR model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.359 .
BCC-CSM2-MR	?	Yes	Xin, Xiaoge; Zhang, Jie; Zhang, Fang; Wu, Tongwen; Shi, Xueli; Li, Jianglong; Chu, Min; Liu, Qianxia; Yan, Jinghui; Ma, Qiang; Wei, Min (2018). BCC BCC-CSM2MR model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1725 .
BCC-ESM1	No	Yes	Zhang, Jie; Wu, Tongwen; Shi, Xueli; Zhang, Fang; Li, Jianglong; Chu, Min; Liu, Qianxia; Yan, Jinghui; Ma, Qiang; Wei, Min (2018). BCC BCC-ESM1 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1734 .
CAMS-CSM1-0	?	?	Rong, Xinyao (2019). CAMS CAMS_CSM1.0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1399 .
CanESM5	No	Yes	Swart, Neil Cameron; Cole, Jason N.S.; Kharin, Viatcheslav V.; Lazare, Mike; Scinocca, John F.; Gillett, Nathan P.; Anstey, James; Arora, Vivek; Christian, James R.; Jiao, Yanjun; Lee, Warren G.; Majaess, Fouad; Saenko, Oleg A.; Seiler, Christian; Seinen, Clint; Shao, Andrew; Solheim, Larry; von Salzen, Knut; Yang, Duo; Winter, Barbara; Sigmond, Michael (2019). CCCma CanESM5 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1303 .
CESM2	No	Yes	Danabasoglu, Gokhan (2019). NCAR CESM2 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.2185 .
CESM2-WACCM	No	Yes	Danabasoglu, Gokhan (2019). NCAR CESM2-WACCM model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.10024 .
CESM2-WACCM-FV2	No	Yes	Danabasoglu, Gokhan (2019). NCAR CESM2-WACCM-FV2 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.11282 .
CNRM-CM6-1	No	No	Voldoire, Aurore (2018). CNRM-CERFACS CNRM-CM6-1 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1375 .
CNRM-ESM2-1	No	?	Seferian, Roland (2018). CNRM-CERFACS CNRM-ESM2-1 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1391 .
E3SM-1-0	No	Yes	Bader, David C.; Leung, Ruby; Taylor, Mark; McCoy, Renata B. (2019). E3SM-Project E3SM1.0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.2294 .
EC-Earth3	No	?	EC-Earth Consortium (EC-Earth) (2019). EC-Earth-Consortium EC-Earth3 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.181 .

CMIP Label	DVM	Phen	Full Citation
EC-Earth3-Veg	Yes	Yes	EC-Earth Consortium (EC-Earth) (2019). EC-Earth-Consortium EC-Earth3-Veg model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.642 .
FGOALS-g3	Yes	Yes	Li, Lijuan (2019). CAS FGOALS-g3 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1783 .
GFDL-CM4	Yes	Yes	Guo, Huan; John, Jasmin G; Blanton, Chris; McHugh, Colleen; Nikonov, Serguei; Radhakrishnan, Aparna; Rand, Kristopher; Zadeh, Niki T.; Balaji, V; Durachta, Jeff; Dupuis, Christopher; Menzel, Raymond; Robinson, Thomas; Underwood, Seth; Vahlenkamp, Hans; Bushuk, Mitchell; Dunne, Krista A.; Dussin, Raphael; Gauthier, Paul PG; Ginoux, Paul; Griffies, Stephen M.; Hallberg, Robert; Harrison, Matthew; Hurlin, William; Malyshev, Sergey; Naik, Vaishali; Paulot, Fabien; Paynter, David J; Ploshay, Jeffrey; Reichl, Brandon G; Schwarzkopf, Daniel M; Seman, Charles J; Shao, Andrew; Silvers, Levi; Wyman, Bruce; Yan, Xiaoqin; Zeng, Yujin; Adcroft, Alistair; Dunne, John P.; Held, Isaac M; Krasting, John P.; Horowitz, Larry W.; Milly, P.C.D; Shevliakova, Elena; Winton, Michael; Zhao, Ming; Zhang, Rong (2018). NOAA-GFDL GFDL-CM4 model output. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1402 .
GFDL-ESM4	Yes	Yes	Krasting, John P.; John, Jasmin G; Blanton, Chris; McHugh, Colleen; Nikonov, Serguei; Radhakrishnan, Aparna; Rand, Kristopher; Zadeh, Niki T.; Balaji, V; Durachta, Jeff; Dupuis, Christopher; Menzel, Raymond; Robinson, Thomas; Underwood, Seth; Vahlenkamp, Hans; Dunne, Krista A.; Gauthier, Paul PG; Ginoux, Paul; Griffies, Stephen M.; Hallberg, Robert; Harrison, Matthew; Hurlin, William; Malyshev, Sergey; Naik, Vaishali; Paulot, Fabien; Paynter, David J; Ploshay, Jeffrey; Schwarzkopf, Daniel M; Seman, Charles J; Silvers, Levi; Wyman, Bruce; Zeng, Yujin; Adcroft, Alistair; Dunne, John P.; Dussin, Raphael; Guo, Huan; He, Jian; Held, Isaac M; Horowitz, Larry W.; Lin, Pu; Milly, P.C.D; Shevliakova, Elena; Stock, Charles; Winton, Michael; Xie, Yuanyu; Zhao, Ming (2018). NOAA-GFDL GFDL-ESM4 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1407 .
GISS-E2-1-G	No	No	NASA Goddard Institute for Space Studies (NASA/GISS) (2018). NASA-GISS GISS-E2.1G model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1400 .
GISS-E2-1-H	No	No	NASA Goddard Institute for Space Studies (NASA/GISS) (2018). NASA-GISS GISS-E2.1H model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1421 .
HadGEM3-GC31-LL	No	No	Ridley, Jeff; Menary, Matthew; Kuhlbrodt, Till; Andrews, Martin; Andrews, Tim (2018). MOHC HadGEM3-GC31-LL model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.419 .
HadGEM3-GC31-MM	No	No	Ridley, Jeff; Menary, Matthew; Kuhlbrodt, Till; Andrews, Martin; Andrews, Tim (2019). MOHC HadGEM3-GC31-MM model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.420 .

CMIP Label	DVM	Phen	Full Citation
INM-CM4-8	?	Yes	Volodin, Evgeny; Mortikov, Evgeny; Gritsun, Andrey; Lykossov, Vasily; Galin, Vener; Diansky, Nikolay; Gusev, Anatoly; Kostykin, Sergey; Iakovlev, Nikolay; Shestakova, Anna; Emelina, Svetlana (2019). INM INM-CM4-8 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1422 .
INM-CM5-0	?	Yes	Volodin, Evgeny; Mortikov, Evgeny; Gritsun, Andrey; Lykossov, Vasily; Galin, Vener; Diansky, Nikolay; Gusev, Anatoly; Kostykin, Sergey; Iakovlev, Nikolay; Shestakova, Anna; Emelina, Svetlana (2019). INM INM-CM5-0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1423 .
IPSL-CM6A-LR	No	Yes	Boucher, Olivier; Denvil, Sébastien; Caubel, Arnaud; Foujols, Marie Alice (2020). IPSL IPSL-CM6A-LR-INCA model output prepared for CMIP6 AerChemMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.13581 .
KACE-1-0-G	Yes	Yes	Byun, Young-Hwa; Lim, Yoon-Jin; Sung, Hyun Min; Kim, Jisun; Sun, Minah; Kim, Byeong-Hyeon (2019). NIMS-KMA KACE1.0-G model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.2241 .
MCM-UA-1-0	No	No	Stouffer, Ronald (2019). U of Arizona MCM-UA-1-0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.2421
MIROC-ES2L	No	Yes	Hajima, Tomohiro; Abe, Manabu; Arakawa, Osamu; Suzuki, Tatsuo; Komuro, Yoshiki; Ogura, Tomoo; Ogochi, Koji; Watanabe, Michio; Yamamoto, Akitomo; Tatebe, Hiroaki; Noguchi, Maki A.; Ohgaito, Rumi; Ito, Akinori; Yamazaki, Dai; Ito, Akihiko; Takata, Kumiko; Watanabe, Shingo; Kawamiya, Michio; Tachiiri, Kaoru (2019). MIROC MIROC-ES2L model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.902 .
MIROC6	No	No	Takemura, Toshihiko (2019). MIROC MIROC6 model output prepared for CMIP6 AerChemMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.9121 .
MPI-ESM-1-2-HAM	Yes	Yes	Neubauer, David; Ferrachat, Sylvaine; Siegenthaler-Le Drian, Colombe; Stoll, Jens; Folini, Doris Sylvia; Tegen, Ina; Wieners, Karl-Hermann; Mauritsen, Thorsten; Stemmler, Irene; Barthel, Stefan; Bey, Isabelle; Daskalakis, Nikos; Heinold, Bernd; Kokkola, Harri; Partridge, Daniel; Rast, Sebastian; Schmidt, Hauke; Schutgens, Nick; Stanelle, Tanja; Stier, Philip; Watson-Parris, Duncan; Lohmann, Ulrike (2019). HAMMOZ-Consortium MPI-ESM1.2-HAM model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1622 .

CMIP Label	DVM	Phen	Full Citation
MPI-ESM1-2-HR	No	Yes	Jungclaus, Johann; Bittner, Matthias; Wieners, Karl-Hermann; Wachsmann, Fabian; Schupfner, Martin; Legutke, Stephanie; Giorgetta, Marco; Reick, Christian; Gayler, Veronika; Haak, Helmuth; de Vrese, Philipp; Raddatz, Thomas; Esch, Monika; Mauritsen, Thorsten; von Storch, Jin-Song; Behrens, Jörg; Brovkin, Victor; Claussen, Martin; Crueger, Traute; Fast, Irina; Fiedler, Stephanie; Hagemann, Stefan; Hohenegger, Cathy; Jahns, Thomas; Kloster, Silvia; Kinne, Stefan; Lasslop, Gitta; Kornblueh, Luis; Marotzke, Jochem; Matei, Daniela; Meraner, Katharina; Mikolajewicz, Uwe; Modali, Kameswarrao; Müller, Wolfgang; Nabel, Julia; Notz, Dirk; Peters, Karsten; Pincus, Robert; Pohlmann, Holger; Pongratz, Julia; Rast, Sebastian; Schmidt, Hauke; Schnur, Reiner; Schulzweida, Uwe; Six, Katharina; Stevens, Bjorn; Voigt, Aiko; Roeckner, Erich (2019). MPI-M MPIESM1.2-HR model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.741 .
MPI-ESM1-2-LR	Yes	Yes	Wieners, Karl-Hermann; Giorgetta, Marco; Jungclaus, Johann; Reick, Christian; Esch, Monika; Bittner, Matthias; Legutke, Stephanie; Schupfner, Martin; Wachsmann, Fabian; Gayler, Veronika; Haak, Helmuth; de Vrese, Philipp; Raddatz, Thomas; Mauritsen, Thorsten; von Storch, Jin-Song; Behrens, Jörg; Brovkin, Victor; Claussen, Martin; Crueger, Traute; Fast, Irina; Fiedler, Stephanie; Hagemann, Stefan; Hohenegger, Cathy; Jahns, Thomas; Kloster, Silvia; Kinne, Stefan; Lasslop, Gitta; Kornblueh, Luis; Marotzke, Jochem; Matei, Daniela; Meraner, Katharina; Mikolajewicz, Uwe; Modali, Kameswarrao; Müller, Wolfgang; Nabel, Julia; Notz, Dirk; Peters, Karsten; Pincus, Robert; Pohlmann, Holger; Pongratz, Julia; Rast, Sebastian; Schmidt, Hauke; Schnur, Reiner; Schulzweida, Uwe; Six, Katharina; Stevens, Bjorn; Voigt, Aiko; Roeckner, Erich (2019). MPI-M MPIESM1.2-LR model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.742 .
MRI-ESM2-0	No	No	Yukimoto, Seiji; Koshiro, Tsuyoshi; Kawai, Hideaki; Oshima, Naga; Yoshida, Kohei; Urakawa, Shogo; Tsujino, Hiroyuki; Deushi, Makoto; Tanaka, Taichu; Hosaka, Masahiro; Yoshimura, Hiromasa; Shindo, Eiki; Mizuta, Ryo; Ishii, Masayoshi; Obata, Atsushi; Adachi, Yukimasa (2019). MRI MRI-ESM2.0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.621 .
NESM3	Yes	Yes	Cao, Jian; Wang, Bin (2019). NUIST NESMv3 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.2021 .
NorCPM1	?	?	Bethke, Ingo; Wang, Yiguo; Counillon, François; Kimmritz, Madlen; Fransner, Filippa; Samuelsen, Annette; Langehaug, Helene Reinertsen; Chiu, Ping-Gin; Bentsen, Mats; Guo, Chungheng; Tjiputra, Jerry; Kirkevåg, Alf; Oliviè, Dirk Jan Leo; Seland, Øyvind; Fan, Yuanchao; Lawrence, Peter; Eldevik, Tor; Keenlyside, Noel (2019). NCC NorCPM1 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.10843 .

CMIP Label	DVM	Phen	Full Citation
NorESM2-LM	No	Yes	Seland, Øyvind; Bentsen, Mats; Olivie, Dirk Jan Leo; Toniazzo, Thomas; Gjermundsen, Ada; Graff, Lise Seland; Debernard, Jens Boldingh; Gupta, Alok Kumar; He, Yanchun; Kirkevåg, Alf; Schwinger, Jörg; Tjiputra, Jerry; Aas, Kjetil Schanke; Bethke, Ingo; Fan, Yuanchao; Griesfeller, Jan; Grini, Alf; Guo, Chungheng; Ilicak, Mehmet; Karset, Inger Helene Hafsahl; Landgren, Oskar Andreas; Liakka, Johan; Moseid, Kine Onsum; Nummelin, Aleks; Spensberger, Clemens; Tang, Hui; Zhang, Zhongshi; Heinze, Christoph; Iversen, Trond; Schulz, Michael (2019). NCC NorESM2-LM model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.502 .
SAM0-UNICON	No	Yes	Park, Sungsu; Shin, Jihoon (2019). SNU SAM0-UNICON model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1489 .
TaiESM1	No	Yes	Lee, Wei-Liang; Liang, Hsin-Chien (2019). AS-RCEC TaiESM1.0 model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.9684 .
UKESM1-0-LL	Yes	Yes	Tang, Yongming; Rumbold, Steve; Ellis, Rich; Kelley, Douglas; Mulcahy, Jane; Sellar, Alistair; Walton, Jeremy; Jones, Colin (2019). MOHC UKESM1.0-LL model output prepared for CMIP6 CMIP. Earth System Grid Federation. doi: https://doi.org/10.22033/ESGF/CMIP6.1569 .

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