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Abstract. TEXT

1 Introduction

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(Craig et al., 1997) (Booth et al., 2012) (Booth et al., 2013) (Huntingford et al., 2009) (Sellers et al., 1996) (Abramowitz, 2012) (Luo et al., 2012) (Williamson et al., 2014) (Kennedy and O’Hagan, 2001) (Brynjarsdóttir and O’Hagan, 2014) (Higdon
10 et al., 2008) (Jones et al., 2005) (Smith et al., 2008) (Gordon et al., 2000) (Pope et al., 2000) (Cox, 2001) (Smith, 2012)
(Williams et al., 2013) (Williams et al., 2014) (Gnanadesikan and Stouffer, 2006) (McKay et al., 1979) (Urban and Fricker,
2010) (Gregoire et al., 2010) (Loveland et al., 2000) (Roustant et al., 2012) (R Core Team, 2016) (Vernon et al., 2010) (Lee
et al., 2016) (Williamson et al., 2013) (Ritz et al., 2015) (McNeill et al., 2013) (Pukelsheim, 1994) (Carslaw et al., 2013)
(Saltelli et al., 1999) (Pujol et al., 2015) (Cox et al., 2004) (Good et al., 2008) (Joetzjer et al., 2013) (Staver et al., 2011) (Malhi
15 et al., 2009) (Yin et al., 2012)

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3 Conclusions

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5 Appendix A

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Author contributions. TEXT

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References

- Abramowitz, G.: Towards a public, standardized, diagnostic benchmarking system for land surface models, *Geoscientific Model Development*, 5, 819–827, doi:10.5194/gmd-5-819-2012, <http://www.geosci-model-dev.net/5/819/2012/>, 2012.
- Booth, B. B. B., Jones, C. D., Collins, M., Totterdell, I. J., Cox, P. M., Sitch, S., Huntingford, C., Betts, R. A., Harris, G. R., and Lloyd, J.:
5 High sensitivity of future global warming to land carbon cycle processes, *Environmental Research Letters*, 7, 024 002, <http://stacks.iop.org/1748-9326/7/i=2/a=024002>, 2012.
- Booth, B. B. B., Bernie, D., McNeall, D., Hawkins, E., Caesar, J., Boulton, C., Friedlingstein, P., and Sexton, D. M. H.: Scenario and modelling uncertainty in global mean temperature change derived from emission-driven global climate models, *Earth System Dynamics*, 4, 95–108, doi:10.5194/esd-4-95-2013, <http://www.earth-syst-dynam.net/4/95/2013/>, 2013.
- 10 Brynjarsdóttir, J. and O’Hagan, A.: Learning about physical parameters: the importance of model discrepancy, *Inverse Problems*, 30, 114 007, <http://stacks.iop.org/0266-5611/30/i=11/a=114007>, 2014.
- Carslaw, K., Lee, L., Reddington, C., Pringle, K., Rap, A., Forster, P., Mann, G., Spracklen, D., Woodhouse, M., Regayre, L., et al.: Large contribution of natural aerosols to uncertainty in indirect forcing, *Nature*, 503, 67–71, 2013.
- Cox, M. P., Betts, A. R., Collins, M., Harris, P. P., Huntingford, C., and Jones, D. C.: Amazonian forest dieback under climate-carbon cycle
15 projections for the 21st century, *Theoretical and Applied Climatology*, 78, 137–156, doi:10.1007/s00704-004-0049-4, <http://dx.doi.org/10.1007/s00704-004-0049-4>, 2004.
- Cox, P. M.: Description of the TRIFFID dynamic global vegetation model, Tech. rep., Technical Note 24, Hadley Centre, United Kingdom Meteorological Office, Bracknell, UK, 2001.
- Craig, P., Goldstein, M., Seheult, A., and Smith, J.: Pressure matching for hydrocarbon reservoirs: a case study in the use of Bayes linear
20 strategies for large computer experiments, in: *Case studies in Bayesian statistics*, edited by Gatsonis, C., Hodges, J., Kass, R., McCulloch, R., Rossi, P., and Singpurwalla, N., vol. 3, pp. 36–93, Springer-Verlag, New York, USA, 1997.
- Gnanadesikan, A. and Stouffer, R. J.: Diagnosing atmosphere-ocean general circulation model errors relevant to the terrestrial biosphere using the Koppen climate classification, *Geophysical Research Letters*, 33, n/a–n/a, doi:10.1029/2006GL028098, <http://dx.doi.org/10.1029/2006GL028098>, 122701, 2006.
- 25 Good, P., Lowe, J. A., Collins, M., and Moufouma-Okia, W.: An objective tropical Atlantic sea surface temperature gradient index for studies of south Amazon dry-season climate variability and change, *Philosophical Transactions of the Royal Society of London B: Biological Sciences*, 363, 1761–1766, doi:10.1098/rstb.2007.0024, <http://rstb.royalsocietypublishing.org/content/363/1498/1761>, 2008.
- Gordon, C., Cooper, C., Senior, A. C., Banks, H., Gregory, M. J., Johns, C. T., Mitchell, B. J. F., and Wood, A. R.: The simulation of SST, sea ice extents and ocean heat transports in a version of the Hadley Centre coupled model without flux adjustments, *Climate Dynamics*,
30 16, 147–168, doi:10.1007/s003820050010, <http://dx.doi.org/10.1007/s003820050010>, 2000.
- Gregoire, L. J., Valdes, P. J., Payne, A. J., and Kahana, R.: Optimal tuning of a GCM using modern and glacial constraints, *Climate Dynamics*, 37, 705–719, doi:10.1007/s00382-010-0934-8, <http://dx.doi.org/10.1007/s00382-010-0934-8>, 2010.
- Higdon, D., Gattiker, J., Williams, B., and Rightley, M.: Computer Model Calibration Using High-Dimensional Output, *Journal of the American Statistical Association*, 103, 570–583, doi:10.1198/016214507000000888, <http://dx.doi.org/10.1198/016214507000000888>, 2008.
- 35 Huntingford, C., Lowe, J. A., Booth, B. B. B., Jones, C. D., Harris, G. R., Gohar, L. K., and Meir, P.: Contributions of carbon cycle uncertainty to future climate projection spread, *Tellus B*, 61, 355–360, doi:10.1111/j.1600-0889.2009.00414.x, <http://dx.doi.org/10.1111/j.1600-0889.2009.00414.x>, 2009.

- Joetzer, E., Douville, H., Delire, C., and Ciais, P.: Present-day and future Amazonian precipitation in global climate models: CMIP5 versus CMIP3, *Climate Dynamics*, 41, 2921–2936, doi:10.1007/s00382-012-1644-1, <http://dx.doi.org/10.1007/s00382-012-1644-1>, 2013.
- Jones, C., Gregory, J., Thorpe, R., Cox, P., Murphy, J., Sexton, D., and Valdes, P.: Systematic optimisation and climate simulation of FAMOUS, a fast version of HadCM3, *Climate Dynamics*, 25, 189–204, doi:10.1007/s00382-005-0027-2, <http://dx.doi.org/10.1007/s00382-005-0027-2>, 2005.
- Kennedy, M. and O’Hagan, A.: Bayesian calibration of computer models, *Journal of the Royal Statistical Society: Series B (Statistical Methodology)*, 63, 425–464, 2001.
- Lee, L. A., Reddington, C. L., and Carslaw, K. S.: On the relationship between aerosol model uncertainty and radiative forcing uncertainty, *Proceedings of the National Academy of Sciences*, doi:10.1073/pnas.1507050113, <http://www.pnas.org/content/early/2016/02/04/1507050113.abstract>, 2016.
- Loveland, T. R., Reed, B. C., Brown, J. F., Ohlen, D. O., Zhu, Z., Yang, L., and Merchant, J. W.: Development of a global land cover characteristics database and IGBP DISCover from 1 km AVHRR data, *International Journal of Remote Sensing*, 21, 1303–1330, doi:10.1080/014311600210191, <http://dx.doi.org/10.1080/014311600210191>, 2000.
- Luo, Y. Q., Randerson, J. T., Abramowitz, G., Bacour, C., Blyth, E., Carvalhais, N., Ciais, P., Dalmonech, D., Fisher, J. B., Fisher, R., Friedlingstein, P., Hibbard, K., Hoffman, F., Huntzinger, D., Jones, C. D., Koven, C., Lawrence, D., Li, D. J., Mahecha, M., Niu, S. L., Norby, R., Piao, S. L., Qi, X., Peylin, P., Prentice, I. C., Riley, W., Reichstein, M., Schwalm, C., Wang, Y. P., Xia, J. Y., Zaehle, S., and Zhou, X. H.: A framework for benchmarking land models, *Biogeosciences*, 9, 3857–3874, doi:10.5194/bg-9-3857-2012, <http://www.biogeosciences.net/9/3857/2012/>, 2012.
- Malhi, Y., Aragão, L. E. O. C., Galbraith, D., Huntingford, C., Fisher, R., Zelazowski, P., Sitch, S., McSweeney, C., and Meir, P.: Exploring the likelihood and mechanism of a climate-change-induced dieback of the Amazon rainforest, *Proceedings of the National Academy of Sciences*, 106, 20610–20615, doi:10.1073/pnas.0804619106, <http://www.pnas.org/content/106/49/20610.abstract>, 2009.
- McKay, M., Beckman, R., and Conover, W.: A comparison of three methods for selecting values of input variables in the analysis of output from a computer code, *Technometrics*, pp. 239–245, 1979.
- McNeill, D. J., Challenor, P. G., Gattiker, J. R., and Stone, E. J.: The potential of an observational data set for calibration of a computationally expensive computer model, *Geoscientific Model Development*, 6, 1715–1728, doi:10.5194/gmd-6-1715-2013, <http://www.geosci-model-dev.net/6/1715/2013/>, 2013.
- Pope, D. V., Gallani, L. M., Rowntree, R. P., and Stratton, A. R.: The impact of new physical parametrizations in the Hadley Centre climate model: HadAM3, *Climate Dynamics*, 16, 123–146, doi:10.1007/s003820050009, <http://dx.doi.org/10.1007/s003820050009>, 2000.
- Pujol, G., Iooss, B., with contributions from Sebastien Da Veiga, A. J., Fruth, J., Gilquin, L., Guillaume, J., Gratiot, L. L., Lemaitre, P., Ramos, B., and Touati, T.: sensitivity: Sensitivity Analysis, <https://CRAN.R-project.org/package=sensitivity>, r package version 1.11.1, 2015.
- Pukelsheim, F.: The three sigma rule, *The American Statistician*, 48, 88–91, 1994.
- R Core Team: R: A Language and Environment for Statistical Computing, R Foundation for Statistical Computing, Vienna, Austria, <https://www.R-project.org/>, 2016.
- Ritz, C., Edwards, T. L., Durand, G., Payne, A. J., Peyaud, V., and Hindmarsh, R. C.: Potential sea-level rise from Antarctic ice-sheet instability constrained by observations, *Nature*, 528, 115–118, 2015.

- Roustant, O., Ginsbourger, D., and Deville, Y.: DiceKriging, DiceOptim: Two R Packages for the Analysis of Computer Experiments by Kriging-Based Metamodeling and Optimization, *Journal of Statistical Software*, 51, 1–55, doi:10.18637/jss.v051.i01, <https://www.jstatsoft.org/index.php/jss/article/view/v051i01>, 2012.
- Saltelli, A., Tarantola, S., and Chan, K. P.-S.: A Quantitative Model-Independent Method for Global Sensitivity Analysis of Model Output, *Technometrics*, 41, 39–56, doi:10.1080/00401706.1999.10485594, <http://amstat.tandfonline.com/doi/abs/10.1080/00401706.1999.10485594>, 1999.
- Sellers, P., Randall, D., Collatz, G., Berry, J., Field, C., Dazlich, D., Zhang, C., Collelo, G., and Bounoua, L.: A Revised Land Surface Parameterization (SiB2) for Atmospheric GCMS. Part I: Model Formulation, *Journal of Climate*, 9, 676–705, doi:10.1175/1520-0442(1996)009<0676:ARLSPF>2.0.CO;2, [http://dx.doi.org/10.1175/1520-0442\(1996\)009<0676:ARLSPF>2.0.CO;2](http://dx.doi.org/10.1175/1520-0442(1996)009<0676:ARLSPF>2.0.CO;2), 1996.
- 10 Smith, R. S.: The FAMOUS climate model (versions XFXWB and XFHCC): description update to version XDBUA, *Geoscientific Model Development*, 5, 269–276, doi:10.5194/gmd-5-269-2012, <http://www.geosci-model-dev.net/5/269/2012/>, 2012.
- Smith, R. S., Gregory, J. M., and Osprey, A.: A description of the FAMOUS (version XDBUA) climate model and control run, *Geoscientific Model Development*, 1, 53–68, doi:10.5194/gmd-1-53-2008, <http://www.geosci-model-dev.net/1/53/2008/>, 2008.
- Staver, A. C., Archibald, S., and Levin, S. A.: The Global Extent and Determinants of Savanna and Forest as Alternative Biome States, *Science*, 334, 230–232, doi:10.1126/science.1210465, <http://science.sciencemag.org/content/334/6053/230>, 2011.
- 15 Urban, N. M. and Fricker, T. E.: A comparison of Latin hypercube and grid ensemble designs for the multivariate emulation of an Earth system model, *Computers & Geosciences*, 36, 746–755, 2010.
- Vernon, I., Goldstein, M., and Bower, R.: Galaxy formation: a Bayesian uncertainty analysis, *Bayesian Analysis*, 5, 619–669, 2010.
- Williams, J. H. T., Smith, R. S., Valdes, P. J., Booth, B. B. B., and Osprey, A.: Optimising the FAMOUS climate model: inclusion of global carbon cycling, *Geoscientific Model Development*, 6, 141–160, doi:10.5194/gmd-6-141-2013, <http://www.geosci-model-dev.net/6/141/2013/>, 2013.
- 20 Williams, J. H. T., Totterdell, I. J., Halloran, P. R., and Valdes, P. J.: Numerical simulations of oceanic oxygen cycling in the FAMOUS Earth-System model: FAMOUS-ES, version 1.0, *Geoscientific Model Development*, 7, 1419–1431, doi:10.5194/gmd-7-1419-2014, <http://www.geosci-model-dev.net/7/1419/2014/>, 2014.
- 25 Williamson, D., Goldstein, M., Allison, L., Blaker, A., Challenor, P., Jackson, L., and Yamazaki, K.: History matching for exploring and reducing climate model parameter space using observations and a large perturbed physics ensemble, *Climate dynamics*, 41, 1703–1729, 2013.
- Williamson, D., Blaker, A. T., Hampton, C., and Salter, J.: Identifying and removing structural biases in climate models with history matching, *Climate Dynamics*, 45, 1299–1324, doi:10.1007/s00382-014-2378-z, <http://dx.doi.org/10.1007/s00382-014-2378-z>, 2014.
- 30 Yin, L., Fu, R., Shevliakova, E., and Dickinson, R. E.: How well can CMIP5 simulate precipitation and its controlling processes over tropical South America?, *Climate Dynamics*, 41, 3127–3143, doi:10.1007/s00382-012-1582-y, <http://dx.doi.org/10.1007/s00382-012-1582-y>, 2012.

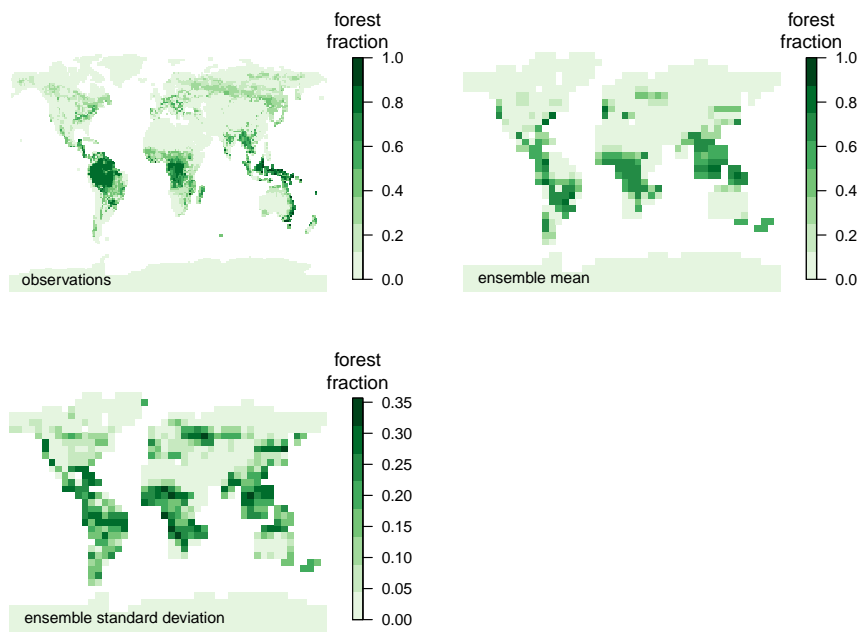


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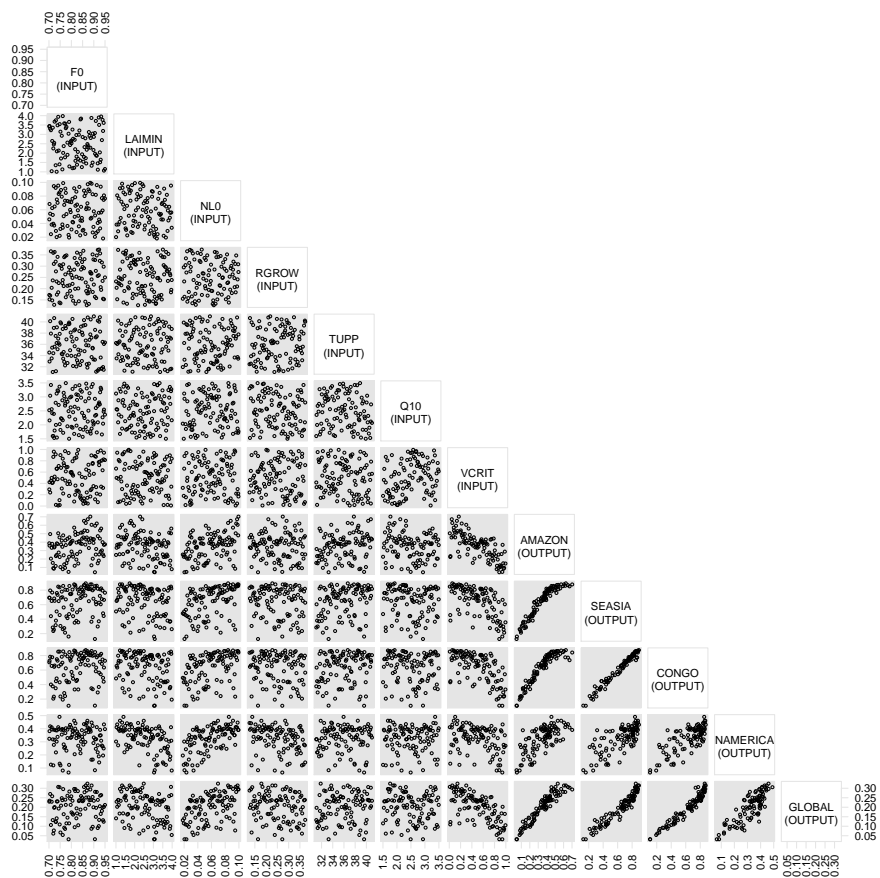


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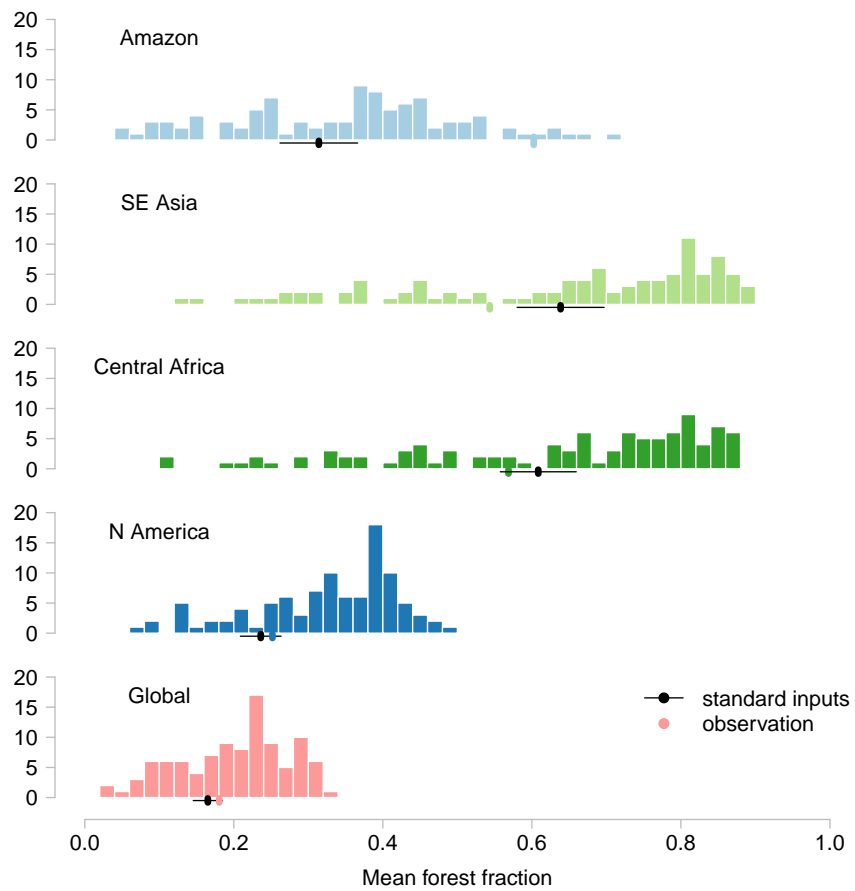


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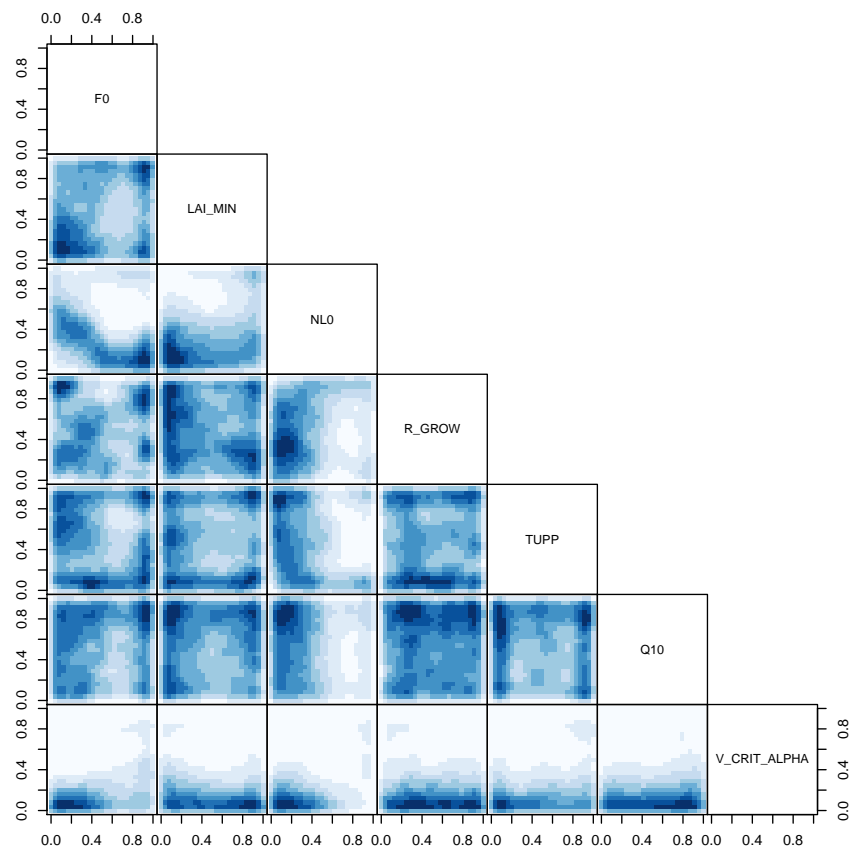


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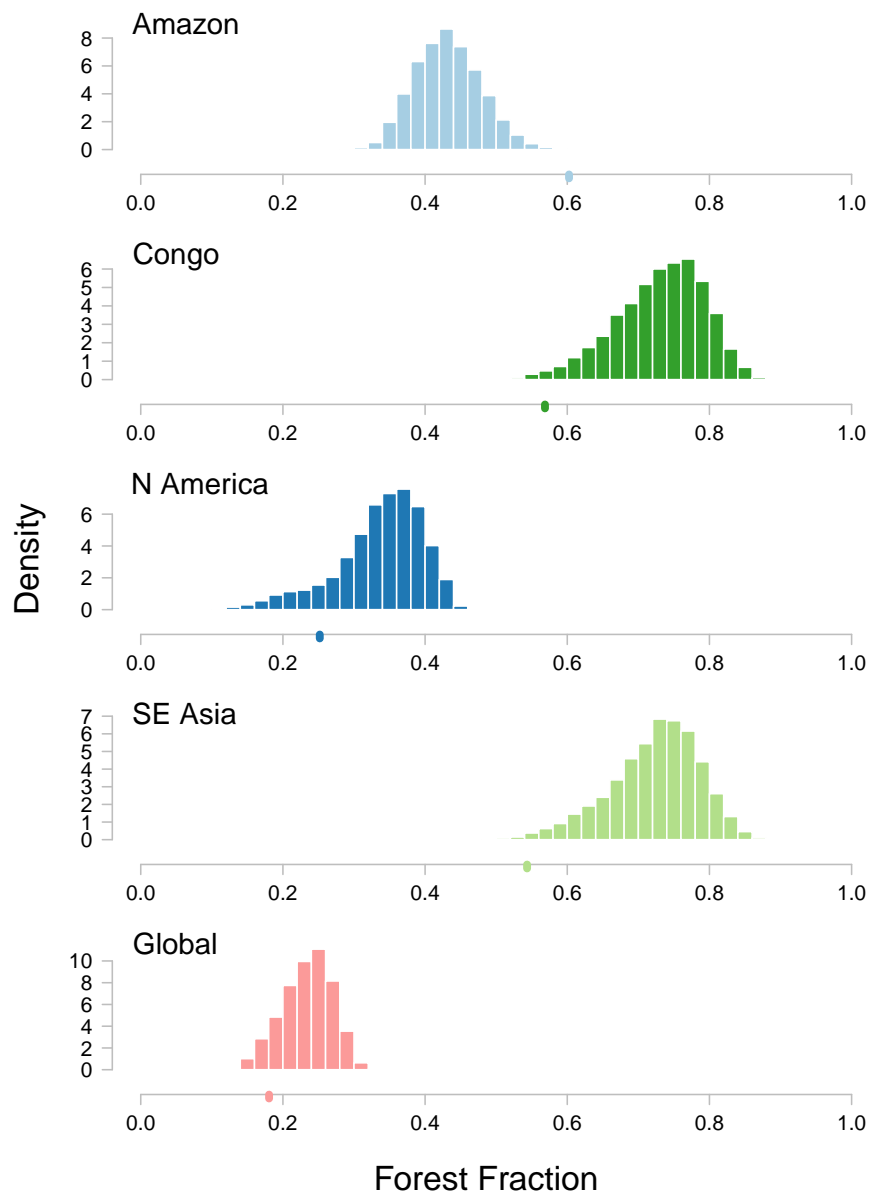


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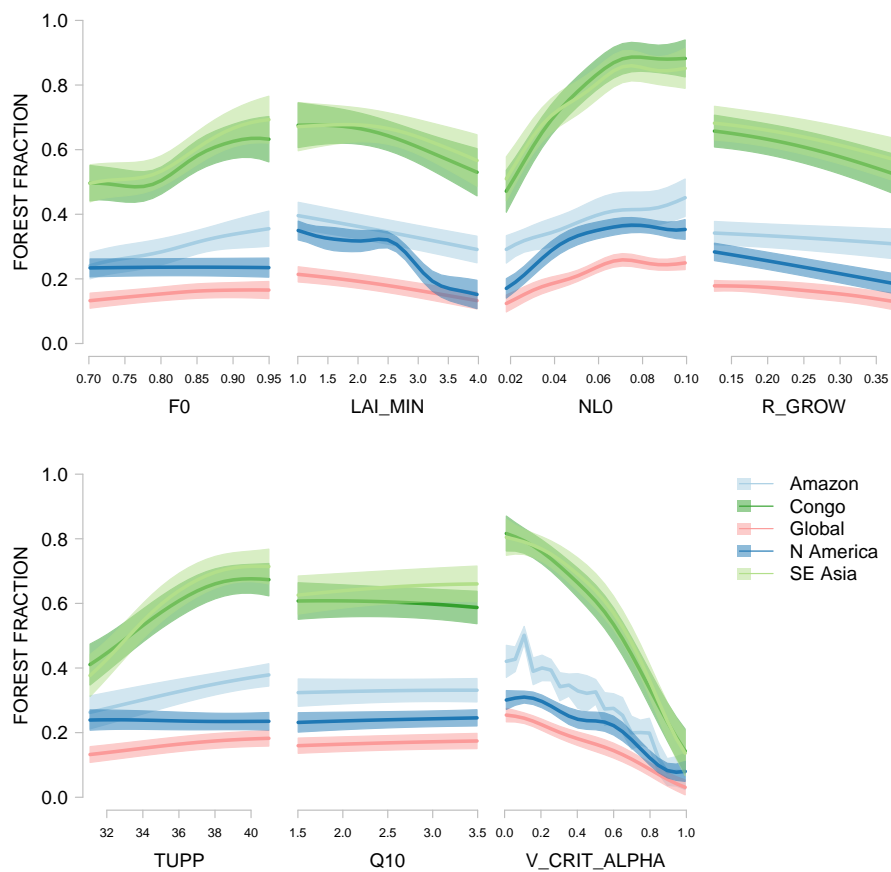


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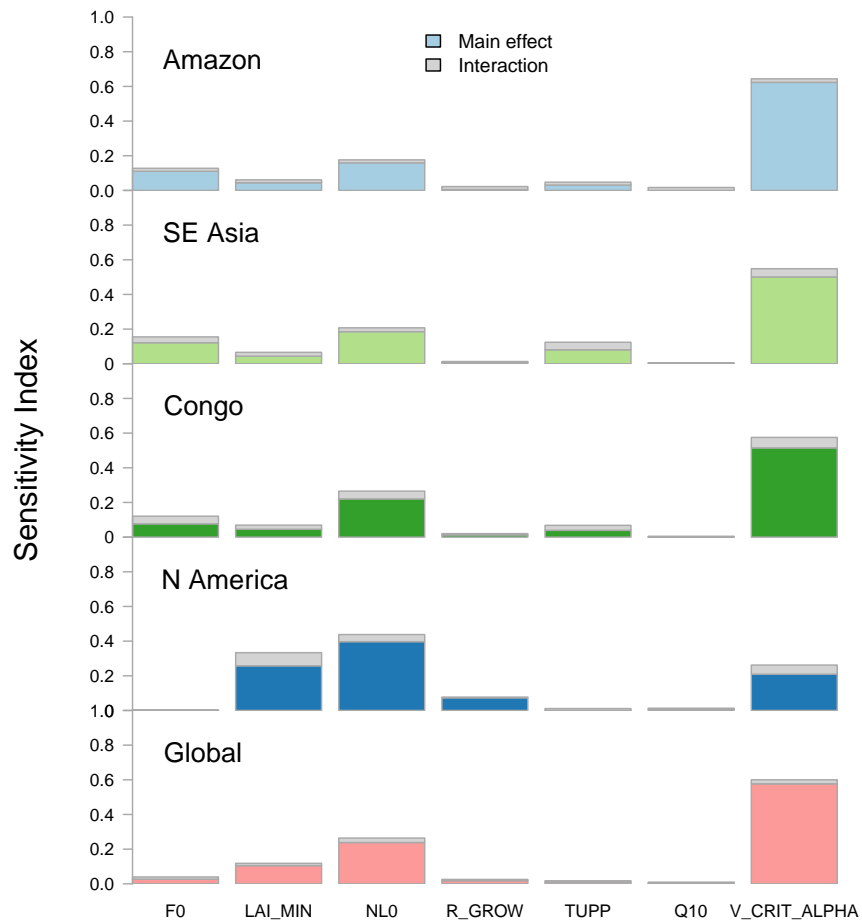


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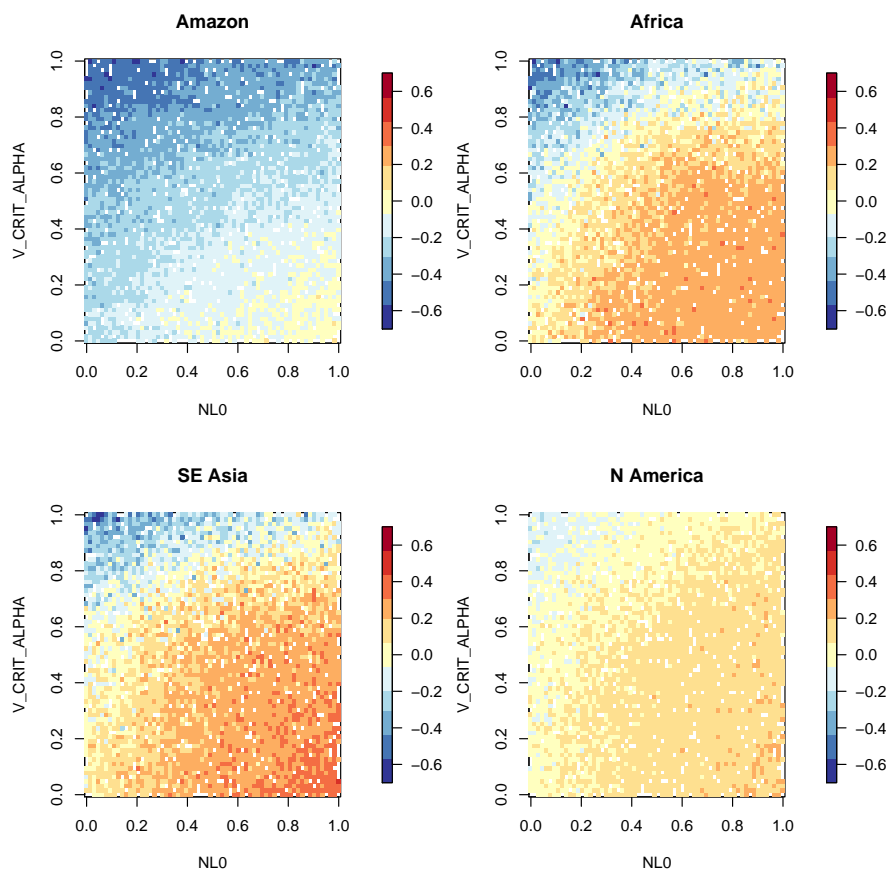


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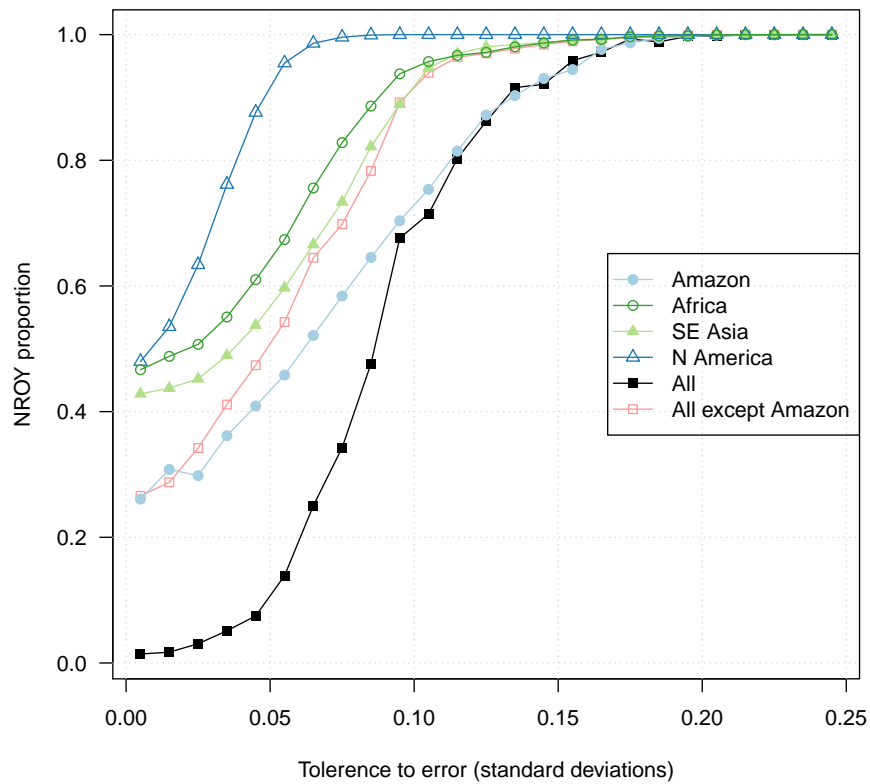


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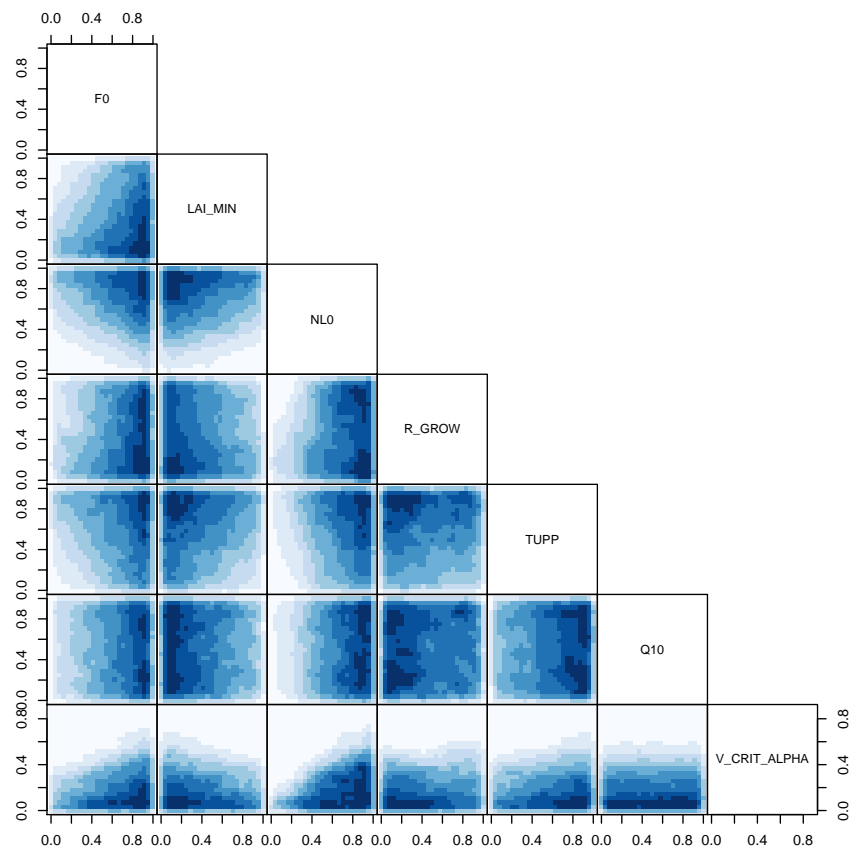


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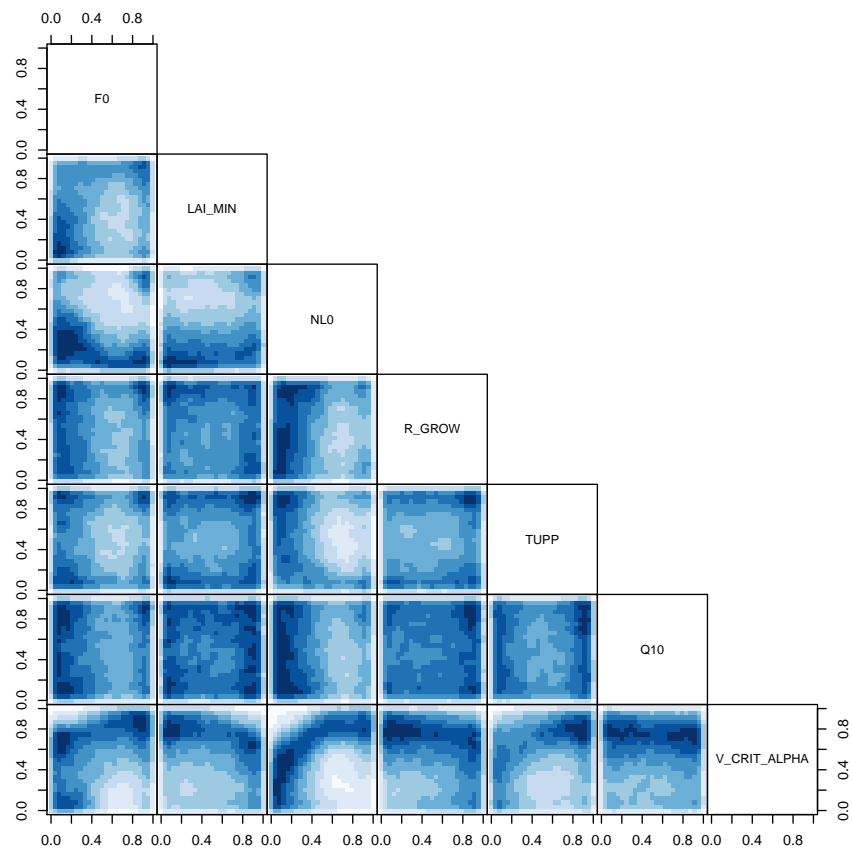


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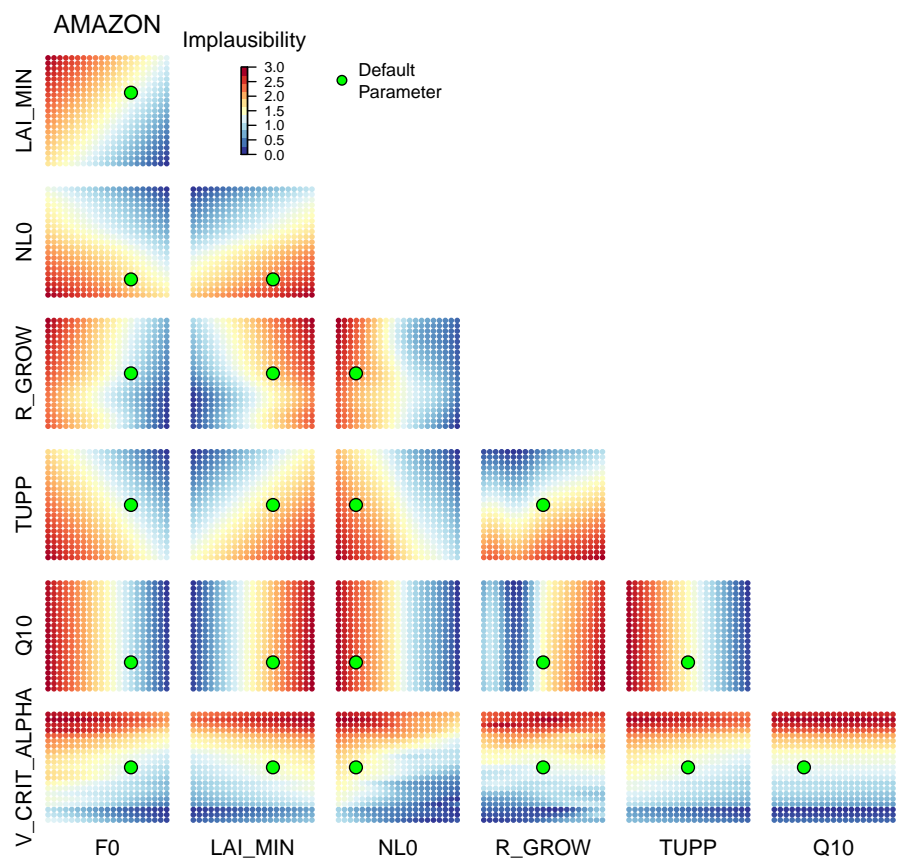


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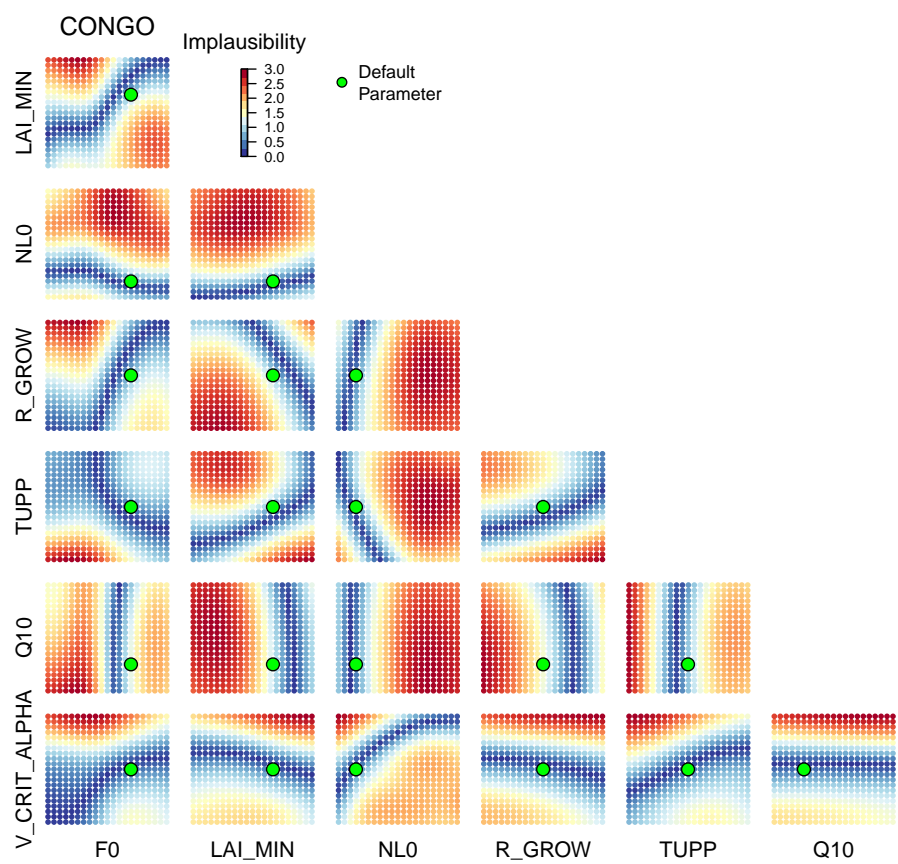


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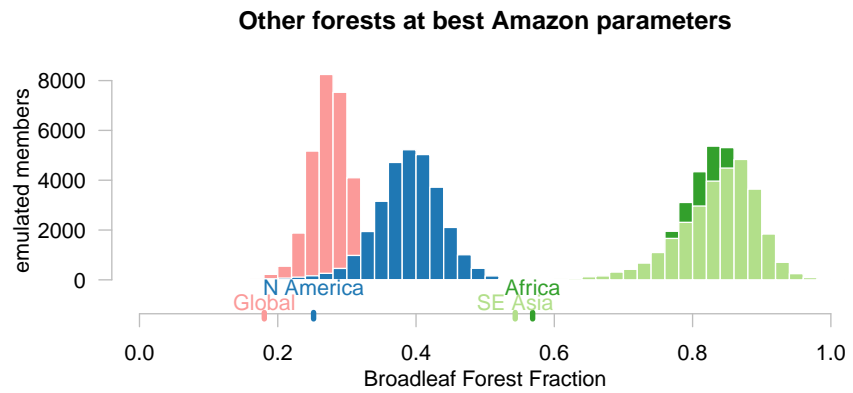
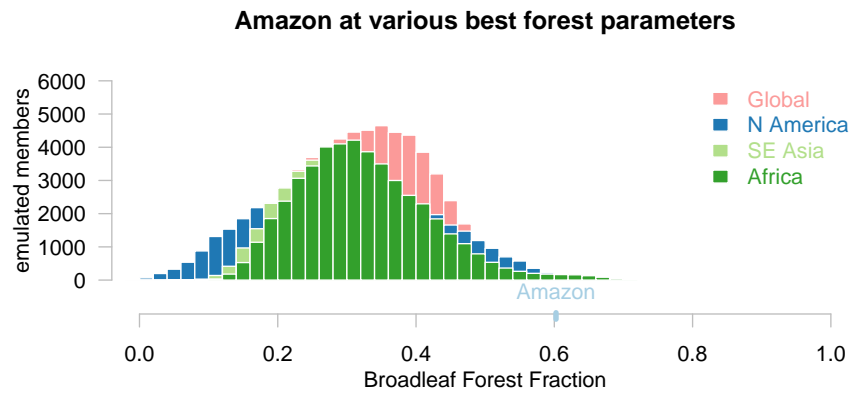


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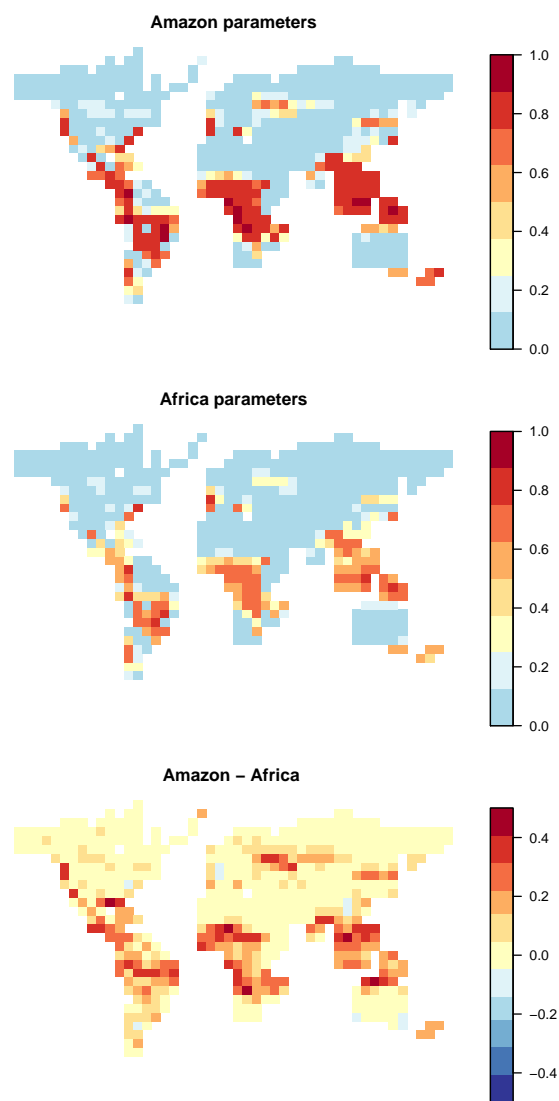


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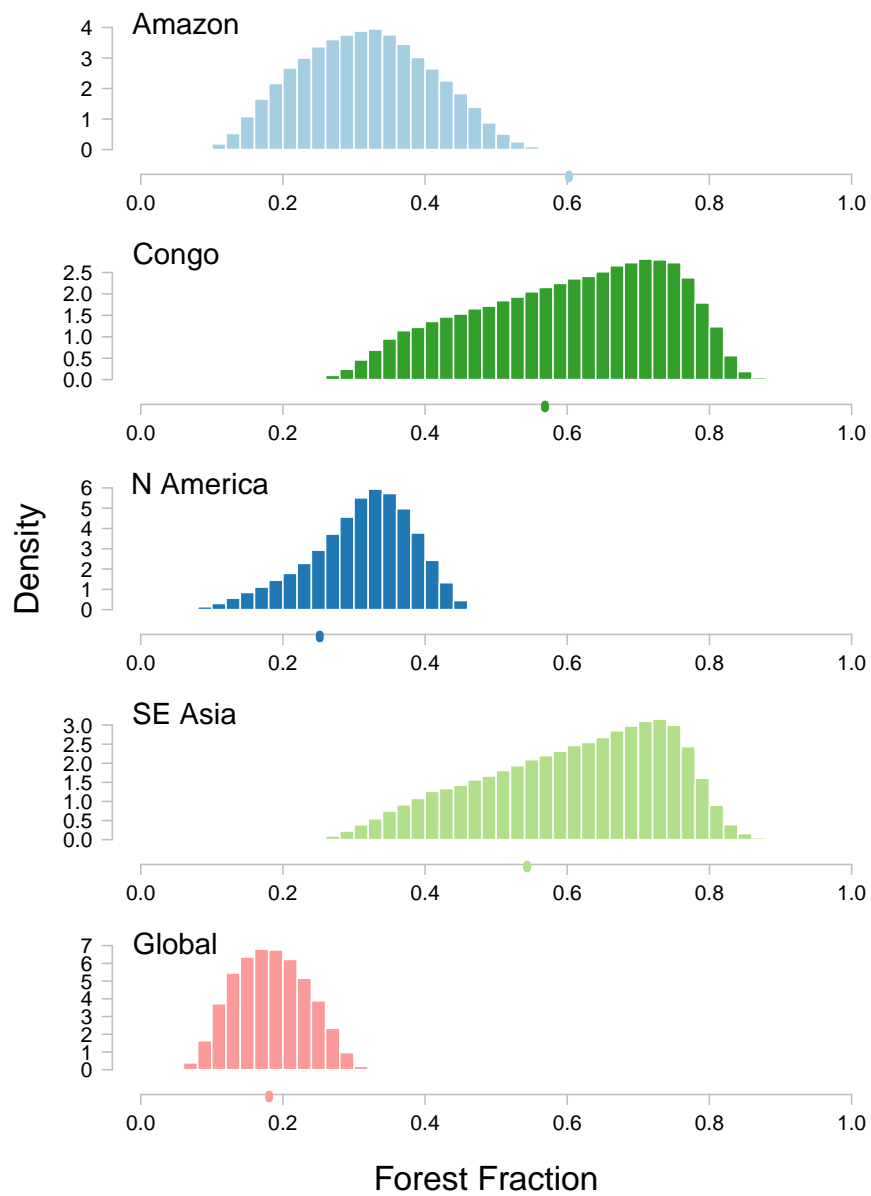


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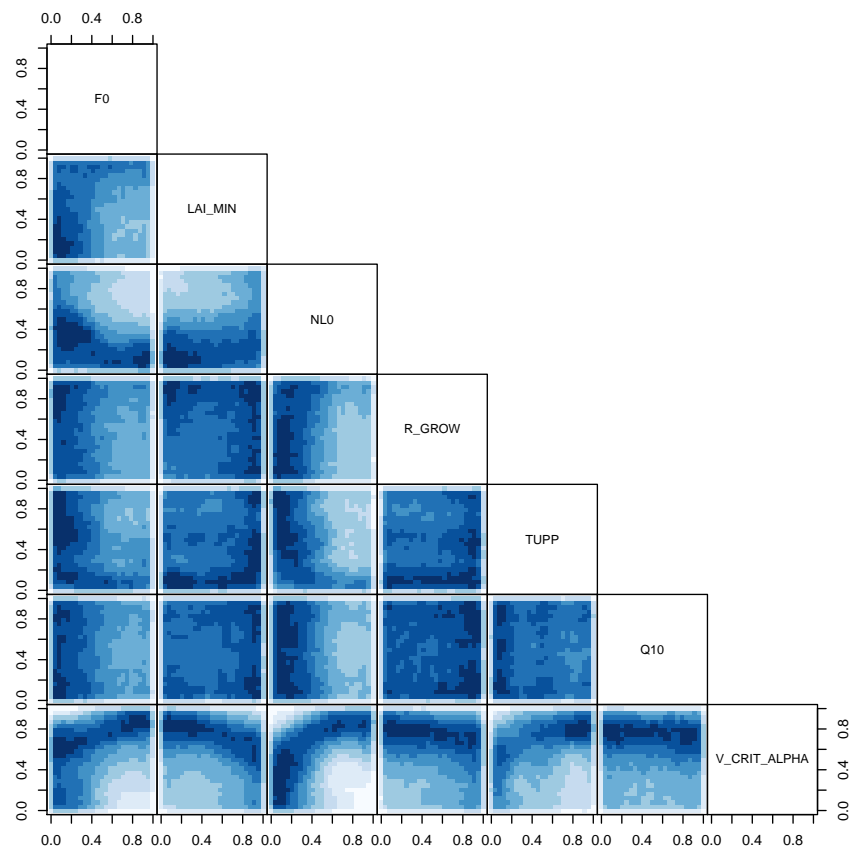


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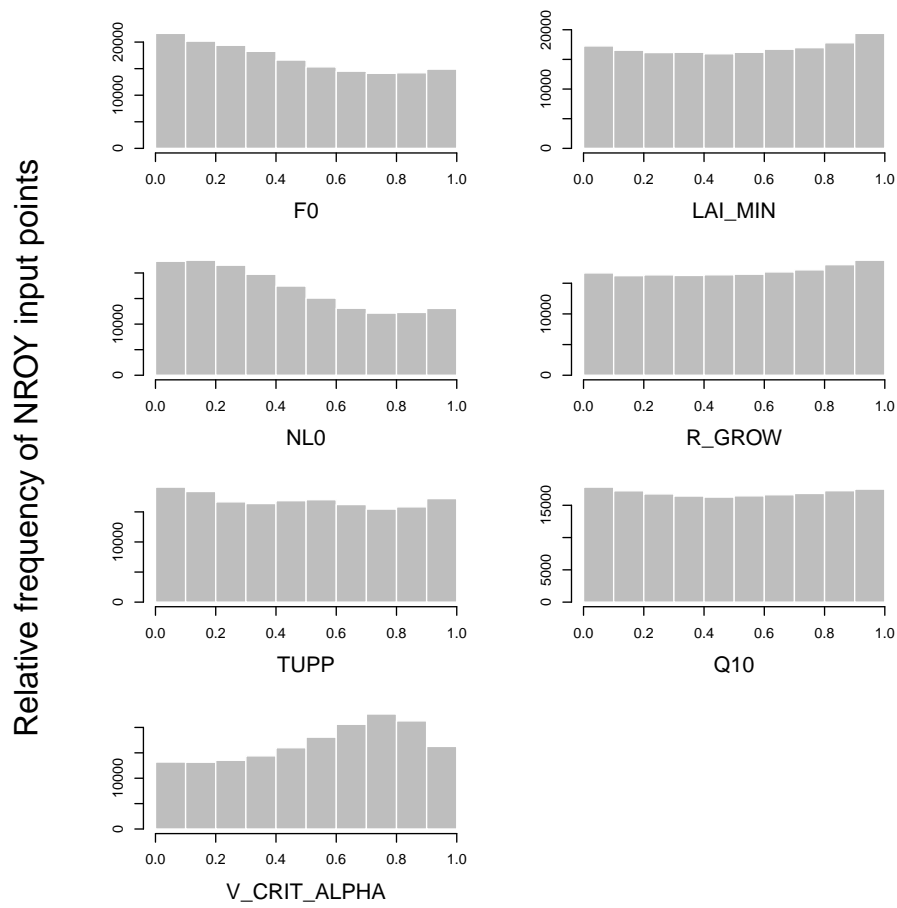


Figure 18. TEXT