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Variability and uncertainty in flux-site-scale net ecosystem exchange simulations based on machine learning and remote sensing: a systematic evaluation

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Supplementary Figures and Tables

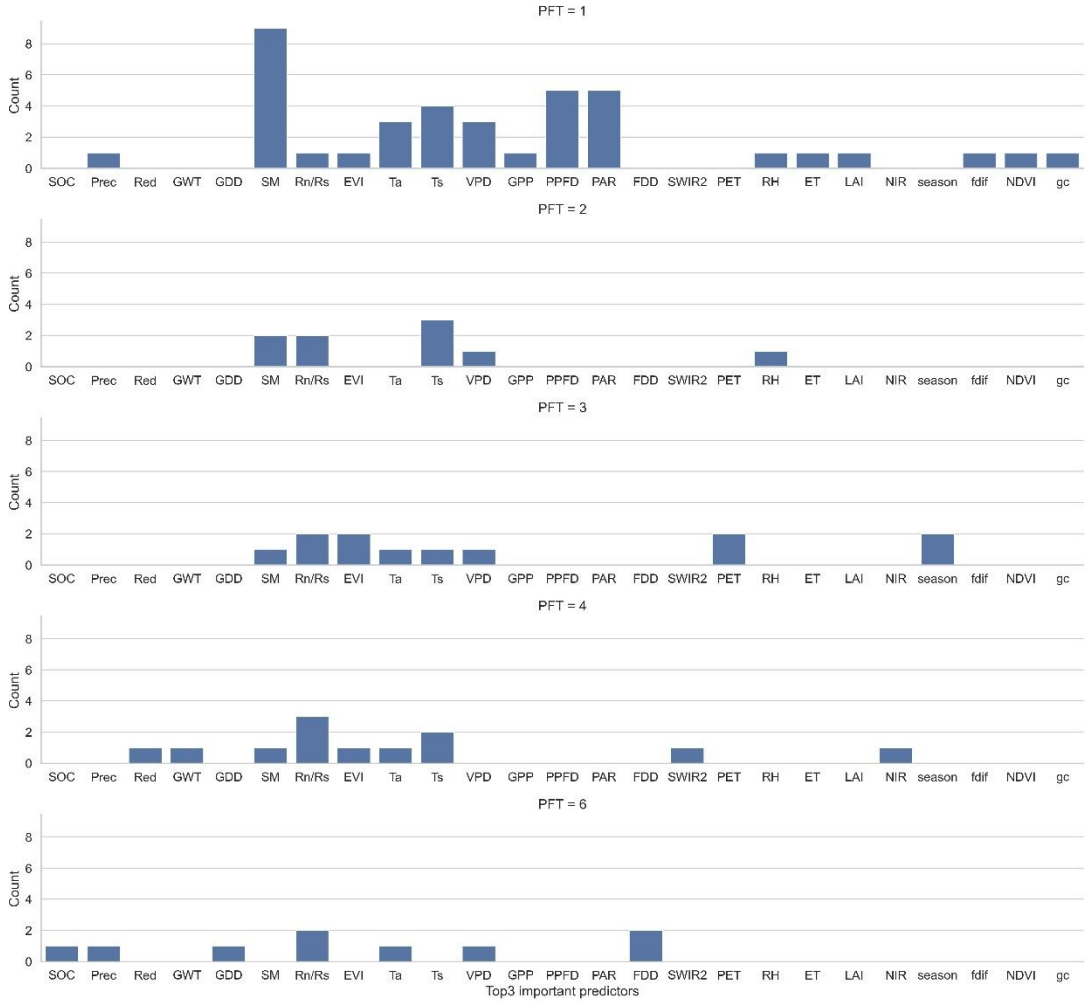

Figure S1. Counts of variables ranked in the top three for importance in different PFTs (1-forest, 2-grassland, 3-cropland, 4-wetland, 6-tundra). Predictors: growing degree days (GDD), freezing degree days (FDD), soil organic content (SOC), precipitation (Prec), red band (Red), groundwater table depth (GWT), growing degree days (GDD), soil moisture (SM), net radiation/solar radiation (Rn/Rs), Enhanced vegetation index (EVI), air temperature (Ta), soil temperature (Ts), vapor-pressure deficit (VPD), gross primary productivity (GPP), photosynthetic photon flux density (PPFD), photosynthetically active radiation (PAR), freezing degree days (FDD), short-wave infrared band (SWIR2), potential evapotranspiration (PET), relative humidity (RH), evapotranspiration (ET), leaf area index (LAI), the near-infrared band (NIR), the diffuse fraction (fdir), canopy conductance (gc).

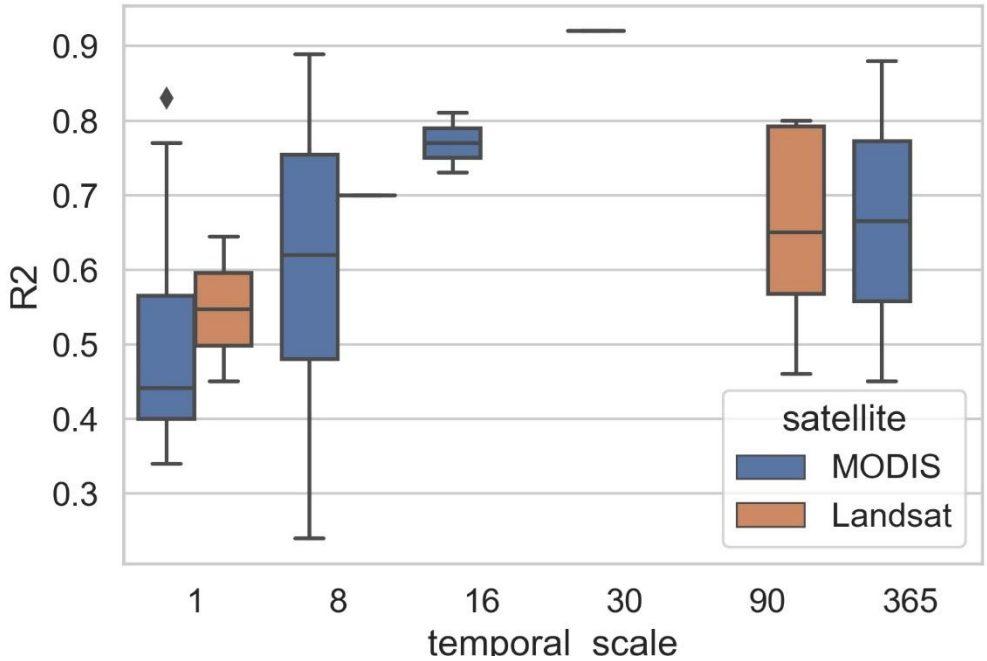

Figure S2. The performance of the models with MODIS and Landsat data used across temporal scales.

Table S1. Journal filters for quality control of studies.

Agriculture/Forestry Journals	**Hydrology/Meteorology Journals**	**Biology/Ecology Journals**	**Remote Sensing Journals**	**Other Journals**
Agricultural and Forest Meteorology, Agriculture Ecosystems and Environment, Agricultural Water Management	Journal of Hydrology, Journal of Hydrometeorology, Agricultural Water Management, Hydrological Processes, Hydrology and Earth System Sciences, Advances in Water Resources, Journal of Geophysical Research Atmospheres, Water Resources Research, Atmospheric Chemistry and Physics	Biogeosciences, Journal of Geophysical Research Biogeosciences, Global Change Biology, Global Biogeochemical Cycles, Ecological Modelling, Ecological Applications, Ecosystems, Plant Cell and Environment, Biogeochemistry, Functional Ecology	Remote Sensing of Environment, IEEE Transactions on Geoscience and Remote Sensing	Science of The Total Environment, Geophysical Research Letters, Geoscientific Model Development, Environmental Research Letters, Scientific Data, Environmental Pollution, Journal of Environmental Management

Table S2. The papers included in this meta-analysis.

Papers included in the meta analysis	Berryman et al., 2018; Braybrook et al., 2021; Cho et al., 2021; Cleverly et al., 2020; Cui et al., 2021; Evrendilek, 2013; Fu et al., 2014, 2009; Huemmrich et al., 2019; Ichii et al., 2017; Jung et al., 2011; Kato and Tang, 2008; Kondo et al., 2015; Krasnova et al., 2019; Liu et al., 2016, 2018; Lucas-Moffat et al., 2018; Madani et al., 2017; Melesse and Hanley, 2005; Moffat et al., 2010; Mueller et al., 2010; Papale and Valentini, 2003; Park et al., 2018; Reed et al., 2021; Reitz et al., 2021; Ryu et al., 2018; Schubert et al., 2010; Stiegler et al., 2019; Sun et al., 2020, 2019; Teklemariam et al., 2010; Tian et al., 2017; Tramontana et al., 2016; Ueyama et al., 2013; Virkkala et al., 2021; Xiao et al., 2008; Zeng et al., 2020; Zhang et al., 2014; Zhou et al., 2020

References

Berryman, E. M., Vanderhoof, M. K., Bradford, J. B., Hawbaker, T. J., Henne, P. D., Burns, S. P., Frank, J. M., Birdsey, R. A., and Ryan, M. G.: Estimating Soil Respiration in a Subalpine Landscape Using Point, Terrain, Climate, and Greenness Data, 123, 3231–3249, https://doi.org/10.1029/2018JG004613, 2018.

Braybrook, C. A., Scott, N. A., Treitz, P. M., and Humphreys, E. R.: Interannual Variability of Summer Net Ecosystem CO2 Exchange in High Arctic Tundra, 126, https://doi.org/10.1029/2020JG006094, 2021.

Cho, S., Kang, M., Ichii, K., Kim, J., Lim, J.-H., Chun, J.-H., Park, C.-W., Kim, H. S., Choi, S.-W., Lee, S.-H., Indrawati, Y. M., and Kim, J.: Evaluation of forest carbon uptake in South Korea using the national flux tower network, remote sensing, and data-driven technology, 311, https://doi.org/10.1016/j.agrformet.2021.108653, 2021.

Cleverly, J., Vote, C., Isaac, P., Ewenz, C., Harahap, M., Beringer, J., Campbell, D. I., Daly, E., Eamus, D., He, L., Hunt, J., Grace, P., Hutley, L. B., Laubach, J., McCaskill, M., Rowlings, D., Rutledge Jonker, S., Schipper, L. A., Schroder, I., Teodosio, B., Yu, Q., Ward, P. R., Walker, J. P., Webb, J. A., and Grover, S. P. P.: Carbon, water and energy fluxes in agricultural systems of Australia and New Zealand, 287, https://doi.org/10.1016/j.agrformet.2020.107934, 2020.

Cui, X., Goff, T., Cui, S., Menefee, D., Wu, Q., Rajan, N., Nair, S., Phillips, N., and Walker, F.: Predicting carbon and water vapor fluxes using machine learning and novel feature ranking algorithms, 775, https://doi.org/10.1016/j.scitotenv.2021.145130, 2021.

Evrendilek, F.: Quantifying biosphere-atmosphere exchange of CO2 using eddy covariance, wavelet denoising, neural networks, and multiple regression models, 171–172, 1–8, https://doi.org/10.1016/j.agrformet.2012.11.002, 2013.

Fu, D., Chen, B., Zhang, H., Wang, J., Black, T. A., Amiro, B., Bohrer, G., Bolstad, P., Coulter, R., Rahman, F., Dunn, A., Harry, M., Meyers, T., and Verma, S.: Estimating landscape net ecosystem exchange at high spatial-temporal resolution based on Landsat data, an improved upscaling model framework, and eddy covariance flux measurements, 141, 90–104, https://doi.org/10.1016/j.rse.2013.10.029, 2014.

Fu, Y., Zheng, Z., Yu, G., Hu, Z., Sun, X., Shi, P., Wang, Y., and Zhao, X.: Environmental influences on carbon dioxide fluxes over three grassland ecosystems in China, 6, 2879–2893, https://doi.org/10.5194/bg-6-2879-2009, 2009.

Huemmrich, K. F., Campbell, P., Landis, D., and Middleton, E.: Developing a common globally applicable method for optical remote sensing of ecosystem light use efficiency, 230, https://doi.org/10.1016/j.rse.2019.05.009, 2019.

Ichii, K., Ueyama, M., Kondo, M., Saigusa, N., Kim, J., Alberto, M. C., Ardö, J., Euskirchen, E. S., Kang, M., Hirano, T., Joiner, J., Kobayashi, H., Marchesini, L. B., Merbold, L., Miyata, A., Saitoh, T. M., Takagi, K., Varlagin, A., Bret-Harte, M. S., Kitamura, K., Kosugi, Y., Kotani, A., Kumar, K., Li, S.-G., Machimura, T., Matsuura, Y., Mizoguchi, Y., Ohta, T., Mukherjee, S., Yanagi, Y., Yasuda, Y., Zhang, Y., and Zhao, F.: New data-driven estimation of terrestrial CO2 fluxes in Asia using a standardized database of eddy covariance measurements, remote sensing data, and support vector regression, 122, 767–795, https://doi.org/10.1002/2016JG003640, 2017.

Jung, M., Reichstein, M., Margolis, H. A., Cescatti, A., Richardson, A. D., Arain, M. A., Arneth, A., Bernhofer, C., Bonal, D., Chen, J., Gianelle, D., Gobron, N., Kiely, G., Kutsch, W., Lasslop, G., Law, B. E., Lindroth, A., Merbold, L., Montagnani, L., Moors, E. J., Papale, D., Sottocornola, M., Vaccari, F., and Williams, C.: Global patterns of land-atmosphere fluxes of carbon dioxide, latent heat, and sensible heat derived from eddy covariance, satellite, and meteorological observations, 116, https://doi.org/10.1029/2010JG001566, 2011.

Kato, T. and Tang, Y.: Spatial variability and major controlling factors of CO2 sink strength in Asian terrestrial ecosystems: Evidence from eddy covariance data, 14, 2333–2348, https://doi.org/10.1111/j.1365-2486.2008.01646.x, 2008.

Kondo, M., Ichii, K., Takagi, H., and Sasakawa, M.: Comparison of the data-driven top-down and bottom-up global terrestrial CO2 exchanges: GOSAT CO2 inversion and empirical eddy flux upscaling, 120, 1226–1245, https://doi.org/10.1002/2014JG002866, 2015.

Krasnova, A., Kukumägi, M., Mander, Ü., Torga, R., Krasnov, D., Noe, S. M., Ostonen, I., Püttsepp, Ü., Killian, H., Uri, V., Lõhmus, K., Sõber, J., and Soosaar, K.: Carbon exchange in a hemiboreal mixed forest in relation to tree species composition, 275, 11–23, https://doi.org/10.1016/j.agrformet.2019.05.007, 2019.

Liu, S., Zhuang, Q., He, Y., Noormets, A., Chen, J., and Gu, L.: Evaluating atmospheric CO2 effects on gross primary productivity and net ecosystem exchanges of terrestrial ecosystems in the conterminous United States using the AmeriFlux data and an artificial neural network approach, 220, 38–49, https://doi.org/10.1016/j.agrformet.2016.01.007, 2016.

Liu, Y., Zhou, G., Du, H., Berninger, F., Mao, F., Li, X., Chen, L., Cui, L., Li, Y., Zhu, D., and Xu, L.: Response of carbon uptake to abiotic and biotic drivers in an intensively managed Lei bamboo forest, 223, 713–722, https://doi.org/10.1016/j.jenvman.2018.06.046, 2018.

Lucas-Moffat, A. M., Huth, V., Augustin, J., Brümmer, C., Herbst, M., and Kutsch, W. L.: Towards pairing plot and field scale measurements in managed ecosystems: Using eddy covariance to cross-validate CO2 fluxes modeled from manual chamber campaigns, 256–257, 362–378, https://doi.org/10.1016/j.agrformet.2018.01.023, 2018.

Madani, N., Kimball, J. S., and Running, S. W.: Improving Global Gross Primary Productivity Estimates by Computing Optimum Light Use Efficiencies Using Flux Tower Data, 122, 2939–2951, https://doi.org/10.1002/2017JG004142, 2017.

Melesse, A. M. and Hanley, R. S.: Artificial neural network application for multi-ecosystem carbon flux simulation, 189, 305–314, https://doi.org/10.1016/j.ecolmodel.2005.03.014, 2005.

Moffat, A. M., Beckstein, C., Churkina, G., Mund, M., and Heimann, M.: Characterization of ecosystem responses to climatic controls using artificial neural networks, 16, 2737–2749, https://doi.org/10.1111/j.1365-2486.2010.02171.x, 2010.

Mueller, K. L., Yadav, V., Curtis, P. S., Vogel, C., and Michalak, A. M.: Attributing the variability of eddy-covariance CO2 flux measurements across temporal scales using geostatistical regression for a mixed northern hardwood forest, 24, https://doi.org/10.1029/2009GB003642, 2010.

Papale, D. and Valentini, R.: A new assessment of European forests carbon exchanges by eddy fluxes and artificial neural network spatialization, 9, 525–535, https://doi.org/10.1046/j.1365-2486.2003.00609.x, 2003.

Park, S.-B., Knohl, A., Lucas-Moffat, A. M., Migliavacca, M., Gerbig, C., Vesala, T., Peltola, O., Mammarella, I., Kolle, O., Lavrič, J. V., Prokushkin, A., and Heimann, M.: Strong radiative effect induced by clouds and smoke on forest net ecosystem productivity in central Siberia, 250–251, 376–387, https://doi.org/10.1016/j.agrformet.2017.09.009, 2018.

Reed, D. E., Poe, J., Abraha, M., Dahlin, K. M., and Chen, J.: Modeled Surface-Atmosphere Fluxes From Paired Sites in the Upper Great Lakes Region Using Neural Networks, 126, https://doi.org/10.1029/2021JG006363, 2021.

Reitz, O., Graf, A., Schmidt, M., Ketzler, G., and Leuchner, M.: Upscaling Net Ecosystem Exchange Over Heterogeneous Landscapes With Machine Learning, 126, https://doi.org/10.1029/2020JG005814, 2021.

Ryu, Y., Jiang, C., Kobayashi, H., and Detto, M.: MODIS-derived global land products of shortwave radiation and diffuse and total photosynthetically active radiation at 5 km resolution from 2000, 204, 812–825, https://doi.org/10.1016/j.rse.2017.09.021, 2018.

Schubert, P., Eklundh, L., Lund, M., and Nilsson, M.: Estimating northern peatland CO2 exchange from MODIS time series data, 114, 1178–1189, https://doi.org/10.1016/j.rse.2010.01.005, 2010.

Stiegler, C., Meijide, A., Fan, Y., Ali, A. A., June, T., and Knohl, A.: El Niño-Southern Oscillation (ENSO) event reduces CO2 uptake of an Indonesian oil palm plantation, 16, 2873–2890, https://doi.org/10.5194/bg-16-2873-2019, 2019.

Sun, Q., Meyer, W. S., Koerber, G. R., and Marschner, P.: Rapid recovery of net ecosystem production in a semi-arid woodland after a wildfire, 291, https://doi.org/10.1016/j.agrformet.2020.108099, 2020.

Sun, S., Che, T., Li, H., Wang, T., Ma, C., Liu, B., Wu, Y., and Song, Z.: Water and carbon dioxide exchange of an alpine meadow ecosystem in the northeastern Tibetan Plateau is energy-limited, 275, 283–295, https://doi.org/10.1016/j.agrformet.2019.06.003, 2019.

Teklemariam, T. A., Lafleur, P. M., Moore, T. R., Roulet, N. T., and Humphreys, E. R.: The direct and indirect effects of inter-annual meteorological variability on ecosystem carbon dioxide exchange at a temperate ombrotrophic bog, 150, 1402–1411, https://doi.org/10.1016/j.agrformet.2010.07.002, 2010.

Tian, X., Yan, M., van der Tol, C., Li, Z., Su, Z., Chen, E., Li, X., Li, L., Wang, X., Pan, X., Gao, L., and Han, Z.: Modeling forest above-ground biomass dynamics using multi-source data and incorporated models: A case study over the qilian mountains, 246, 1–14, https://doi.org/10.1016/j.agrformet.2017.05.026, 2017.

Tramontana, G., Jung, M., Schwalm, C. R., Ichii, K., Camps-Valls, G., Ráduly, B., Reichstein, M., Arain, M. A., Cescatti, A., Kiely, G., Merbold, L., Serrano-Ortiz, P., Sickert, S., Wolf, S., and Papale, D.: Predicting carbon dioxide and energy fluxes across global FLUXNET sites with regression algorithms, 13, 4291–4313, https://doi.org/10.5194/bg-13-4291-2016, 2016.

Ueyama, M., Ichii, K., Iwata, H., Euskirchen, E. S., Zona, D., Rocha, A. V., Harazono, Y., Iwama, C., Nakai, T., and Oechel, W. C.: Upscaling terrestrial carbon dioxide fluxes in Alaska with satellite remote sensing and support vector regression, 118, 1266–1281, https://doi.org/10.1002/jgrg.20095, 2013.

Virkkala, A.-M., Aalto, J., Rogers, B. M., Tagesson, T., Treat, C. C., Natali, S. M., Watts, J. D., Potter, S., Lehtonen, A., Mauritz, M., Schuur, E. A. G., Kochendorfer, J., Zona, D., Oechel, W., Kobayashi, H., Humphreys, E., Goeckede, M., Iwata, H., Lafleur, P. M., Euskirchen, E. S., Bokhorst, S., Marushchak, M., Martikainen, P. J., Elberling, B., Voigt, C., Biasi, C., Sonnentag, O., Parmentier, F.-J. W., Ueyama, M., Celis, G., St.Louis, V. L., Emmerton, C. A., Peichl, M., Chi, J., Järveoja, J., Nilsson, M. B., Oberbauer, S. F., Torn, M.

S., Park, S.-J., Dolman, H., Mammarella, I., Chae, N., Poyatos, R., López-Blanco, E., Christensen, T. R., Kwon, M. J., Sachs, T., Holl, D., and Luoto, M.: Statistical upscaling of ecosystem CO2 fluxes across the terrestrial tundra and boreal domain: Regional patterns and uncertainties, 27, 4040–4059, https://doi.org/10.1111/gcb.15659, 2021.

Xiao, J., Zhuang, Q., Baldocchi, D. D., Law, B. E., Richardson, A. D., Chen, J., Oren, R., Starr, G., Noormets, A., Ma, S., Verma, S. B., Wharton, S., Wofsy, S. C., Bolstad, P. V., Burns, S. P., Cook, D. R., Curtis, P. S., Drake, B. G., Falk, M., Fischer, M. L., Foster, D. R., Gu, L., Hadley, J. L., Hollinger, D. Y., Katul, G. G., Litvak, M., Martin, T. A., Matamala, R., McNulty, S., Meyers, T. P., Monson, R. K., Munger, J. W., Oechel, W. C., Paw U, K. T., Schmid, H. P., Scott, R. L., Sun, G., Suyker, A. E., and Torn, M. S.: Estimation of net ecosystem carbon exchange for the conterminous United States by combining MODIS and AmeriFlux data, 148, 1827–1847, https://doi.org/10.1016/j.agrformet.2008.06.015, 2008.

Zeng, J., Matsunaga, T., Tan, Z.-H., Saigusa, N., Shirai, T., Tang, Y., Peng, S., and Fukuda, Y.: Global terrestrial carbon fluxes of 1999–2019 estimated by upscaling eddy covariance data with a random forest, 7, https://doi.org/10.1038/s41597-020-00653-5, 2020.

Zhang, L., Guo, H., Jia, G., Wylie, B., Gilmanov, T., Howard, D., Ji, L., Xiao, J., Li, J., Yuan, W., Zhao, T., Chen, S., Zhou, G., and Kato, T.: Net ecosystem productivity of temperate grasslands in northern China: An upscaling study, 184, 71–81, https://doi.org/10.1016/j.agrformet.2013.09.004, 2014.

Zhou, Y., Li, X., Gao, Y., He, M., Wang, M., Wang, Y., Zhao, L., and Li, Y.: Carbon fluxes response of an artificial sand-binding vegetation system to rainfall variation during the growing season in the Tengger Desert, 266, https://doi.org/10.1016/j.jenvman.2020.110556, 2020.