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Open Access Earth System Science Data Discussions

The JapanFlux2024 dataset for eddy covariance observations covering Japan and East Asia from 1990 to 2023

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Abstract. Eddy covariance observations play a pivotal role in understanding the land−atmosphere exchange of energy, water, carbon dioxide (CO_2), and other trace gases, as well as the global carbon cycle and earth system. To promote the networking of individual measurements and the sharing of data, FLUXNET links regional networks of researchers studying land−atmosphere processes. JapanFlux was established in 2006 as a country branch of AsiaFlux. Despite the growing number of shared data globally, the availability in Asia is currently limited. In this study, we developed an open dataset of the eddy covariance observations for Japan and East Asia, called JapanFlux2024, that was conducted by researchers affiliated with Japanese research institutions. The dataset consists of data collected at 79 sites with 652 site-years from 1990 to 2023. The data format is fully compatible with the recent FLUXNET data product, FLUXNET2015. Here, we present the data description and data processing and show the value of processed fluxes of sensible heat, latent heat, and CO_2. The dataset will facilitate important studies for Japan and East Asia, such as land-atmosphere interactions, improvement of process models, and upscaling fluxes using machine learning and remote sensing technology as well as bridge collaborations between Asia and FLUXNET.

1 Introduction

The global network of micrometeorological flux observations, FLUXNET (Delwiche et al., 2024; https://fluxnet.org/), plays a pivotal role in multi-disciplinary fields, such as land−atmosphere interactions, global biogeochemical cycles, and earth system science (Baldocchi et al., 2024; Bonan et al., 2012). FLUXNET started in 1997 as a global network of eddy covariance observations that provides data on land−atmosphere exchanges of energy, water, carbon dioxide (CO_2), methane (CH_4), and other trace gases by measuring direct turbulent transfer. The quasi-continuous eddy covariance observations revealed variations of land−atmosphere exchange at the diurnal, seasonal, interannual, and decadal scales, ranging from site (Takamura et al., 2023; Ueyama et al., 2024f) to global scales (Beer et al., 2010; Keenan et al., 2023; Ueyama et al., 2020a).

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The eddy flux communities have developed publicly open databases to promote the multidisciplinary sciences. FLUXNET has periodically released the open datasets for eddy covariance observations: La Thuile Database (252 sites in 2007; Verma et al., 2014; https://fluxnet.org/data/la-thuile-dataset/), and FLUXNET2015 (212 sites in 2015; Pastorello et al., 2020). Together with the global carbon project (Friedlingstein et al., 2023; www.globalcarbonproject.org), FLUXNET also provided a topical dataset, FLUXNET-CH_4 (Delwiche et al., 2021), which promotes understanding of wetland CH_4 emissions across the globe (Knox et al., 2019; Ueyama et al., 2023). Multiple open databases for the environmental sciences have also been developed for understanding CO_2 fluxes in high-latitude ecosystems (Virkkala et al., 2021) and soil respiration (Bond-Lamberty et al., 2020).

Asia has ca. ~60% of the total world population, and thus humans have been intensively modifying forest land cover in this region for food and energy production. Such land use changes in combination with climate change are likely to impact the regional and global carbon and water cycling. These issues are the greatest environmental concerns for the survival of the human population. Flux studies using eddy covariance observations were conducted since the early 1990s for agricultural fields, wetlands, lakes, plantations, primary and secondary forests, disturbed ecosystems, and urban areas. In Asia, although private databases for eddy covariance measurements were developed (Hirata et al., 2008; Ichii et al., 2017; Saigusa et al., 2013), no open databases have yet been developed except the AsiaFlux database (https://asiaflux.net/), which does not provide consistent gap-filling and flux partitioning.

JapanFlux (https://www.japanflux.org/) was established in 2006 as a national branch of AsiaFlux (Kang and Cho, 2021; Mizoguchi et al., 2009) for the promotion of a network of micrometeorological measurements by researchers affiliated with Japanese research institutions. The mission of JapanFlux is to promote micrometeorological measurements and their collaborations with each other, researchers from other countries, and other research fields (e.g., remote sensing and modeling). Measurements by Japanese institutions have been conducted in Japan and other regions of East Asia (Mizoguchi et al., 2009; Saigusa et al., 2013) since the early 1990s for understanding energy, water, carbon, and greenhouse gas exchanges at various land surfaces.

In this study, we developed JapanFlux2024, the first publicly open dataset by JapanFlux that consists of micrometeorological data measured since the early 1990s. The data format is fully compatible with the most recent FLUXNET data product, FLUXNET2015. The dataset is prepared with consistent post−processing, such as gap-filling and flux partitioning, and provides data at various temporal resolutions of half-hourly/hourly, daily, weekly, monthly, and annual intervals. The dataset consists of data collected at 79 sites with 652 site-years. The dataset promotes collaborations between researchers in Japan and other countries and improves our understanding of land-atmosphere interactions.

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2 Data and methods

The JapanFlux2024 dataset is compatible with the datasets provided by FLUXNET (e.g., FLUXNET2015). According to the processing strategy of Pastorello et al., (2020), the JapanFlux2024 dataset was developed in four steps: (1) data submission by site teams, (2) formatting data in a FLUXNET format, (3) gap-filling and flux partitioning, and (4) preparing subsets and complete datasets data compatible with the FLUXNET data products (Fig. 1). Meta data files, so-called Biological, Ancillary, Disturbance, and Metadata (BADM), were also prepared. The data are available from the data portal (https://ads.nipr.ac.jp/japan-flux2024/) under the data management system, Arctic and Antarctic Data archive System (ADS). Under the ADS, a digital object identifier (DOI) was provided for each site (Table 1). The processing pipeline mentioned in this data paper represent steps downstream of "Filling gaps in meteorology with ERA5"in Fig. 1.

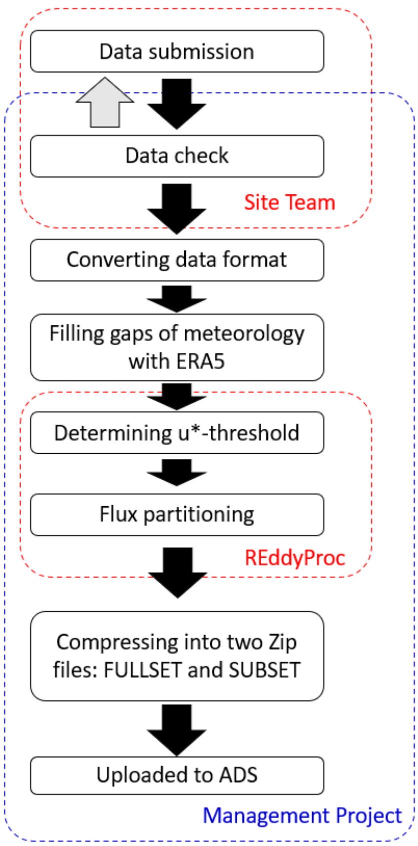

Figure 1. Flow chart of data processing in the JapanFlux2024 dataset. Details in each step and meaning of abbreviations are shown in the text.

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Table 1. Information about sites included in the JapanFlux2024 dataset.

Site Code (BADM)	Country	Country ID	Site Name	Latitude (degree)	Longitude (degree)	Elevation (m)	Köppen climate	IGBP (land use)	Status	Years	Reference	doi
RU-Tur	Russia	RU	Tura	64.208888	100.463555	250	Dfc	DNF	Ongoing	04	Nakai et al. (2008)	Matsuura (2024)
RU-Neb	Russia	RU	Neleger Burnt Forest	62.325937	129.487342	221	Dfd	GRA	Completed	99-00	Iwahana et al. (2005)	Machimura (2024a)
RU-Nel	Russia	RU	Neleger larch forest	62.315615	129.499964	223	Dfd	DNF	Completed	99-06	Iwahana et al. (2005)	Machimura (2024b)
RU-Nec	Russia	RU	Neleger Cutover	62.314844	129.500075	221	Dfd	OSH	Completed	01-06	Iwahana et al. (2005)	Machimura (2024c)
RU-Spl	Russia	RU	Yakutsk Spasskaya Pad larch	62.25471	129.618543	217	Dfc	DNF	Ongoing	04-14	Ohta et al. (2008)	Maximov et al. (2024b)
RU-Spp	Russia	RU	Yakutsk Pine	62.241291	129.651336	216	Dfc	ENF	Completed	04-08	Hamada et al. (2004)	Kotani et al. (2024)
RU-Elg	Russia	RU	Elgeeii forest station	60.01551563	133.8240123	203	Dfd	DNF	Ongoing	10-18	Kotani et al. (2014)	Maximov et al. (2024a)
MN-Skt	Mongolia	MN	Southern Khentei Taiga	48.351861	108.654333	1630	Dwc	DNF	Completed	03-06	Li et al. (2005b)	Asanuma (2024b)
MN-Udl	Mongolia	MN	Udleg practice forest	48.25638888	106.8511111	1342	Dwc	DNF	Ongoing	10-12	Miyazaki et al. (2014)	Ishikawa (2024)
MN-Nlk	Mongolia	MN	Nalaikh grassland	47.693592	107.489342	1531	BSk	GRA	Completed	15-20	Wang et al. (2023)	Wang et al. (2024b)
MN-	Mongol	MN	Hustai grassland	47.594	105.85	1227	BSk	GRA	Comp	15-20	Wang et al.	Wang et al.

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Hst	ia			131	6439				leted		(2023)	(2024a)
MN-Kbu	Mongolia	MN	Kherlenbayan Ulaan	47.213972	108.737333	1235	Bsk	GRA	Completed	03-09	Li et al. (2005a)	Asanuma (2024a)
CN-Lsh	China	CN	Laoshan	45.279839	127.578206	340	Cfc	DNF	Ongoing	02-06	Wang et al. (2005)	Saigusa and Wang (2024)
JP-Sr1	Japan	JP	Sarobetsu Mire Moss	45.104722	141.688194	6	Dfb	WET	Completed	07-10	Hirano et al. (2016)	Hirano (2024a)
JP-Sr2	Japan	JP	Sarobetsu Mire Sasa	45.103611	141.680833	4	Dfb	WET	Completed	07-10	Hirano et al. (2016)	Hirano (2024b)
JP-Tse	Japan	JP	CC-LaG Teshio Experimental Forest	45.055808	142.107122	79.47	Dfb	DNF	Ongoing	01-22	Takagi et al. (2009)	Takagi and Takahashi (2024)
JP-Mbf	Japan	JP	Moshiri Birch Forest Site	44.38416667	142.3186111	596	Af	DBF	Completed	03-11	Nakai et al. (2006)	Nakai et al (2024a)
JP-Mmf	Japan	JP	Moshiri Mixd Forest Site	44.32194444	142.2613889	343	Af	MF	Completed	03-11	Nakai et al. (2006)	Nakai et al (2024b)
JP-Bby	Japan	JP	Bibai bog	43.32296	141.81079	17	Dfb	WET	Completed	12-21	Ueyama et al. (2020c)	Ueyama et al. (2024a)
JP-Km1	Japan	JP	Kushiro Mire: Onnenai Fen	43.107511	144.330906	4.9	Dfb	WET	Completed	94-96, 98	Miyata et al. (2001)	Harazono (2024j)
JP-Km2	Japan	JP	Kushiro Mire: Akanuma Bog	43.1	144.35	7	Dfb	WET	Completed	98-99	Miyata et al. (2001)	Harazono (2024k)
JP-Sap	Japan	JP	Sapporo forest meteorology research site	42.9868431	141.3853305	174	Dfb	DBF	Ongoing	00-18	Yamanoi et al. (2015)	Mizoguchi and Kitamura (2024)
CN-	China	CN	Inner Mongolia	42.944	120.72	354	Bsk	CRO	Comp	94	Li et al.	Harazono

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In4			maize	13333	66222				leted		(2000)	(2024d)
CN-In2	China	CN	Inner Mongolia grassland	42.933 96389	120.71 09639	355	Bsk	GRA	Completed	91	Li et al. (2000)	Harazono (2024b)
CN-In5	China	CN	Inner Mongolia no grazing	42.933 96389	120.71 09639	355	Bsk	GRA	Completed	92-94	Li et al. (2000)	Harazono (2024e)
CN-In6	China	CN	Inner Mongolia heavy grazing	42.933 96389	120.71 09639	355	Bsk	GRA	Completed	92-94	Li et al. (2000)	Harazono (2024f)
CN-In7	China	CN	Inner Mongolia light grazing	42.933 96389	120.71 09639	355	Bsk	GRA	Completed	92-94	Li et al. (2000)	Harazono (2024g)
CN-In8	China	CN	Inner Mongolia medium grazing	42.933 96389	120.71 09639	355	Bsk	GRA	Completed	92, 94	Li et al. (2000)	Harazono (2024h)
CN-In1	China	CN	Inner Mongolia dune	42.929 70833	120.70 735	356	Bsk	BSV	Completed	90-91	Li et al. (2000)	Harazono (2024a)
CN-In3	China	CN	Inner Mongolia soybean	42.925 57222	120.69 90389	354	Bsk	CRO	Completed	91-93	Li et al. (2000)	Harazono (2024c)
JP-Tmk	Japan	JP	Tomakomai Flux Research Site	42.735 911	141.52 3147	117	Dfb	DNF	Ongoing	01-03, 05-23	Hirano et al. (2017)	Hirano and Hirata (2024)
JP-Toc	Japan	JP	Tomakomai Crane site	42.709 727	141.56 5898	96	Dfb	DBF	Ongoing	10-14	Nakamura et al. (2014)	Nakaji et al. (2024)
JP-Toe	Japan	JP	Tomakomai Experimental Forest	42.698 906	141.57 1488	90	Dfb	DBF	Completed	99-13	Shibata et al. (2005)	Nakaji (2024)
JP-Srk	Japan	JP	Shirakami Beech Forest Site	40.565 556	140.12 7778	340	Dfa	DBF	Ongoing	10-16	Ishida et al. (2009)	Ishida (2024)
JP-Api	Japan	JP	Appi forest meteorology	40.001 7	140.93 75	831	Dfa	DBF	Ongoing	00-22	Yasuda et al. (2012)	Yasuda (2024a)

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			research site									
JP-Mra	Japan	JP	Muramatsu agricultural field	37.690275	139.194429	43	Cfa	CRO	Ongoing	23	Boiarskii and Hasegawa (2019)	Nagano and Hasegawa (2024)
CN-Qhb	China	CN	Qinghai Flux Research Site	37.607432	101.332	3250	BSk	GRA	Ongoing	01-14	Du et ak. (2021)	Du et al. (2024)
JP-Kzw	Japan	JP	Karuizawa	36.406667	138.5725	1385	Dfb	DBF	Completed	01-08	Nakaya et al. (2006)	Nakaya et al. (2024)
JP-Tkb	Japan	JP	Tsukuba Experimental Watershed	36.173379	140.176634	341	Cfa	ENF	Ongoing	20-21	Iida et al. (2020)	Shimizu et al. (2024b)
JP-Tky	Japan	JP	Takayama deciduous broadleaf forest site	36.14616667	137.4231111	1420	Dfb	DBF	Ongoing	98-21	Murayama et al. (2024a)	Murayama et al. (2024b)
JP-Tkc	Japan	JP	Takayama evergreen coniferous forest site	36.139722	137.370833	800	Dfb	ENF	Ongoing	05-22	Saitoh et al. (2010)	Saitoh and Tamagawa (2024)
JP-Tgf	Japan	JP	Terrestrial Environment Research Center, University of Tsukuba	36.11353	140.09488	27	Cfa	GRA	Completed	02-22	Shimoda et al. (2005)	Asanuma and Shimoda (2024)
JP-Klp	Japan	JP	Kasumigaura lotus paddy	36.08	140.24	3	Cfa	CRO	Completed	97-98	Takagi et al. (2003)	Harazono and Takagi

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												(2024)
JP-Mse	Japan	JP	Mase paddy flux site	36.054	140.0269	11	Cfa	CRO	Ongoing	01-09	Saito et al. (2005)	Ono (2024)
JP-Swl	Japan	JP	Suwa Lake Site	36.04657222	138.1083528	758	Dfc	WAT	Ongoing	15-23	Iwata et al. (2018)	Iwata (2024b)
JP-Ksl	Japan	JP	Koshin, Lake Kasumigaura	36.037778	140.404167	0.26(at the water level of Y.P.1.1 m)	Cfa	WAT	Ongoing	07-22	Sugita et al. (2020)	Sugita (2024)
JP-Nsb	Japan	JP	NIAES Soybean	36.024303	140.114975	24	Cfa	CRO	Completed	90	Harazono et al. (1992)	Harazono (2024l)
JP-Yrp	Japan	JP	Yawara Rice paddy	36.00766667	140.0301752	23	Cfa	CRO	Completed	93-95	NA	Harazono (2024m)
JP-Kwg	Japan	JP	Kawagoe forest meteorology research site	35.8725	139.4869	41	Cfa	DBF	Completed	97-02	Yasuda et al. (1998)	Yasuda (2024b)
JP-Saf	Japan	JP	Shinshu University Experimental Forest Site	35.865755	137.932563	907	Dfa	MF	Ongoing	14-19	NA	Iwata and Suzuki (2024)
JP-Nkm	Japan	JP	Nishikoma Site	35.808064	137.833883	2641	Dfb	ENF	Ongoing	18-23	NA	Iwata (2024a)
JP-Fmt	Japan	JP	Field Museum Tama Hills	35.638745	139.379748	168	Cfa	MF	Ongoing	13-23	Matsuda et al. (2015)	Takagi and Matsuda (2024)

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JP-Kgh	Japan	JP	Kugahara urban residensial area	35.582859	139.693543	18.5	Cfa	URB	Completed	01-02	Moriwaki and Kanda (2004)	Kanda and Moriwaki (2024)
JP-Fjy	Japan	JP	Fujiyoshida forest meteorology research site	35.45454	138.76225	1043	Cfa	ENF	Ongoing	00-21	Mizoguchi et al. (2012)	Takanashi et al. (2024a)
JP-Fhk	Japan	JP	Fuji Hokuroku Flux Observation Site	35.443528	138.764722	1100	Cfa	DNF	Ongoing	06-23	Takahashi et al. (2015)	Takahashi et al (2024)
JP-Hrt	Japan	JP	Hiratsuka Rice Paddy	35.362778	139.338056	6.98	Cfa	CRO	Completed	13	Komiya (2015)	Komiya (2024a)
JP-Smf	Japan	JP	Seto Mixed Forest Site	35.261528	137.07875	212	Cfa	MF	Completed	02-16	Matsumoto et al. (2008)	Kotani and Ohta (2024)
JP-Nuf	Japan	JP	Nagoya University Forest	35.15241667	136.9718889	66	Cfa	DBF	Completed	00	Hiyama et al. (2005)	Awal and Ohta (2024a)
JP-Tdf	Japan	JP	Toyota Deciduous Forest	35.03588889	137.1857778	104	Cfa	DBF	Completed	02-04	Awal et al. (2010)	Awal and Ohta (2024b)
JP-Yms	Japan	JP	Yamashiro forest meteorology research site	34.790278	135.840939	270	Cfa	DBF	Ongoing	00-23	Kominami et al. (2008)	Takanashi et al. (2024b)
JP-Ako	Japan	JP	Akou green belt	34.735192	134.374798	10.5	Cfa	EBF	Completed	00-03	Kosugi et al. (2005)	Kosugi and Takanashi (2024)

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JP-Nap	Japan	JP	Nunoike Agricultural Pond	34.77485	134.892442	40	Cfa	WAT	Completed	21-23	NA	Sakabe and Itoh (2024)
JP-Sac	Japan	JP	Sakai City Office	34.573402	135.483013	17	Cfa	URB	Ongoing	08-23	Ueyama and Takano (2022)	Ueyama (2024d)
JP-Izm	Japan	JP	Oizumi Urban Park	34.563469	135.533483	22	Cfa	URB	Completed	15-16	Ueyama and Ando (2016)	Ueyama (2024a)
JP-Om1	Japan	JP	B11 building in Osaka Metropolitan University	34.547177	135.502861	27	Cfa	URB	Ongoing	14-23	Ueyama and Ando (2016)	Ueyama (2024b)
JP-Om2	Japan	JP	Farm field in Osaka Metropolitan University	34.542452	135.508227	50	Cfa	GRA	Ongoing	22-23	NA	Ueyama (2024c)
JP-Hc3	Japan	JP	Hachihama Experimental Farm: Double Crop	34.539672	133.911731	-0.25	Cfa	CRO	Completed	05-09	Takimoto et al. (2010)	Takimoto and Iwata (2024b)
JP-Hc1	Japan	JP	Hachihama Experimental Farm	34.53789167	133.9267972	0	Cfa	CRO	Completed	96	Harazono et al. (1998)	Harazono (2024i)
JP-Hc2	Japan	JP	Hachihama Experimental Farm	34.537518	133.927545	-1	Cfa	CRO	Completed	99-08	Ohtaki (1984)	Takimoto and Iwata (2024a)
JP-Khw	Japan	JP	Kahoku Experiment	33.13658	130.70834	196	Cfa	ENF	Ongoing	00-03,	Shimizu et al. (2015)	Kitamura et al (2024)

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			watershed							07-21		
JP-Ynf	Japan	JP	Yona-Field Tower Site	26.751	128.212667	213	Cfa	EBF	Ongoing	13-22	Matsumoto et al. (2023)	Matsumoto et al. (2024)
TH-Kmw	Thailand	TH	Kog-Ma Wateshed	18.8	98.9	1265	Af	EBF	Completed	05-13	Kume et al. (2007)	Kumagai and Takamura (2024a)
TH-Mmp	Thailand	TH	Mae Moh plantation	18.38333333	99.71666667	380	Aw	DBF	Completed	05-16	Igarashi et al. (2015)	Kumagai and Takamura (2024b)
TH-Kms	Thailand	TH	Kamphaeng Saen Rice Paddy	14.009167	99.984167	4.74	Aw	CRO	Completed	14	Komiya (2015)	Komiya (2024b)
KH-Kpt	Cambodia	KH	Kampong Thom Lowland Dry Evergreen Forest	12.74457978	105.4785661	95	Am	EBF	Ongoing	11-14	Kabeya et al. (2021)	Shimizu et al. (2024a)
MY-Lhp	Malaysia	MY	Lambir Hills National Park	4.201007	114.039079	140	Af	EBF	Completed	09-19	Takamura et al. (2023)	Kumagai et al. (2024)
ID-Puf	Indonesia	ID	Palangkaraya Undrained Forest	-2.323614694	113.9043575	22	Am	EBF	Ongoing	04-19	Hirano et al. (2024)	Hirano and Ohkubo (2024c)
ID-Pbf	Indonesia	ID	Palangkaraya Drained Burnt forest	-2.340796	114.0379	14	Am	OSH	Completed	04-17	Ohkubo et al. (2021)	Hirano and Ohkubo (2024a)
ID-Pdf	Indonesia	ID	Palangkaraya drained forest	-2.346070697	114.036408	26	Am	EBF	Completed	01-17	Hirano et al. (2024)	Hirano and Ohkubo (2024b)

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2.1 Data collections

We collected the micrometeorological measurement data from the site teams, which were identified using the web pages for AsiaFlux (https://www.asiaflux.net/, last access: 11 July 2024) and JapanFlux (https://www.japanflux.org/, last access: 11 July 2024). We also collected information on previous studies that reported micrometeorological measurements from domestic researcher connections and literature surveys. The collected data were from eddy covariance observations that were operated by the site teams affiliated with Japanese research institutes and universities. By this criterion, the dataset covers not only Japan but also other countries, such as Russia, China, Mongolia, Cambodia, Thailand, Malaysia, and Indonesia. Most of the sites were established for long-term monitoring of CO_2 fluxes, but intensive observations for about a week in the 1990s were also included in the dataset. Since the data format differed in each team, we reformatted the file to the FLUXNET format (https://ameriflux.lbl.gov/data/aboutdata/data-variables/, last access: 11 July 2024) after consultation with each site team. Generally, non-gap-filled data were provided by the site teams, but some teams provided gap-filled meteorological and flux data in addition to the non-gap-filled data.

The dataset consists of data from 79 sites with 652 site-years, of which 50 sites are located in Japan (Fig. 2; Table 1). The dataset includes 42 forest sites, 12 grassland sites, 5 wetland sites, 10 cropland sites, 3 lake and pond sites, and 4 sites in urban landscapes. Sites that suffered from various types of disturbance are also included: wind damage by typhoon (JP-Tmk, JP-Sap), fire (RU-Nef, ID-Pdb), harvesting (RU-Nec, JP-Tse), thinning (JP-Fhk), insect outbreak (JP-Api), drainage (ID-Pdf), and mowing (JP-Tgf, JP-Om2). The data records started in 1990 at a soybean cropland in Japan (Harazono et al., 1992), their number increased in the early 2000s, and peaked at 32 sites in 2008 and 2015 (Fig. 3). More recently, the number of data records gradually declined owing to site closured or the fact that the data have not been processed yet. The longest record was 24 years (JP-Tky and JP-Yms; both deciduous broadleaf forests) (Fig. 4). There are 26 sites with observation records of CO_2 flux for more than 10 years and 6 sites with those for more than 20 years (JP-Tse, JP-Tmk, JP-Api, JP-Fjy, JP-Tky, JP-Yms). At 10 sites, data records are available for less than one year. Data for CH_4 flux are available at seven sites (JP-Bby, JP-Swl, JP-Nap, JP-Hrt, JP-Sac, JP-Om1, TH-Kms).

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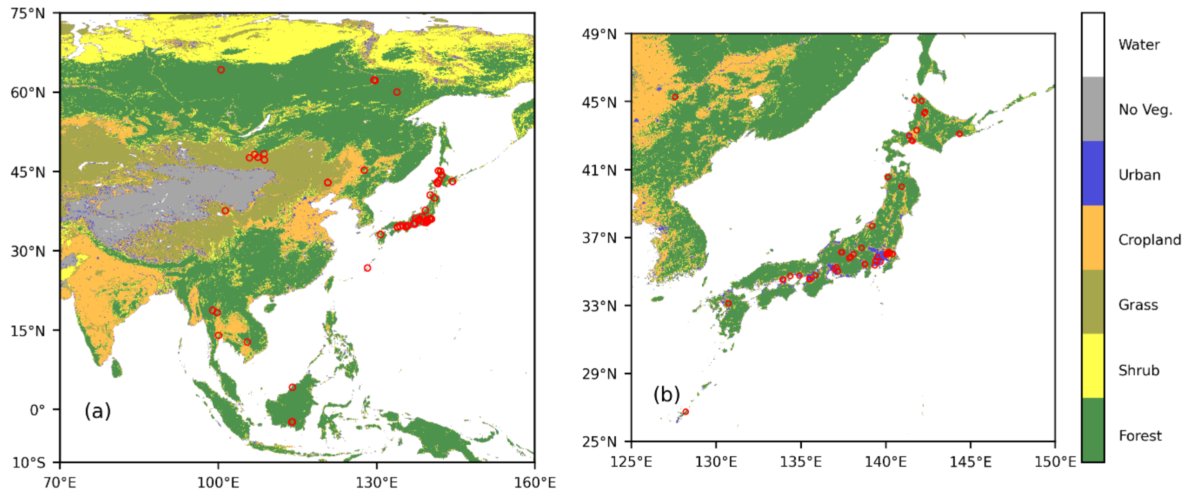

Figure 2. Distributions of the sites that constitute the JapanFlux2024 database on a land cover map provided by the MOD12 product (version 6.1; Sulla-Menashe et al., 2019): a map of Asia region (a) and an enlarged map showing Japan (b).

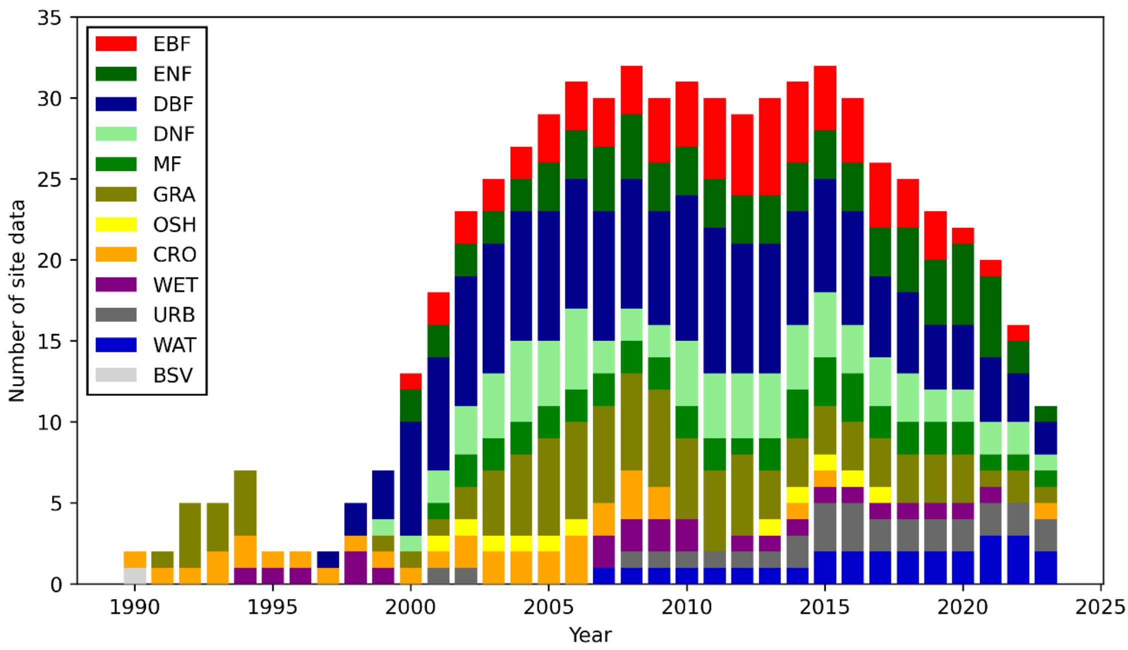

Figure 3. Number of site data records in each year. Land cover types: evergreen broadleaf forest (EBF), evergreen needleleaf forest (ENF), deciduous broadleaf forest (DBF), deciduous needleleaf forest (DNF), mixed forest (MF), grassland (GRA), open shrubland (OSH), cropland (CRO), wetland (WET), urban (URB), lake (WAT), and barren sparse vegetation (BSV).

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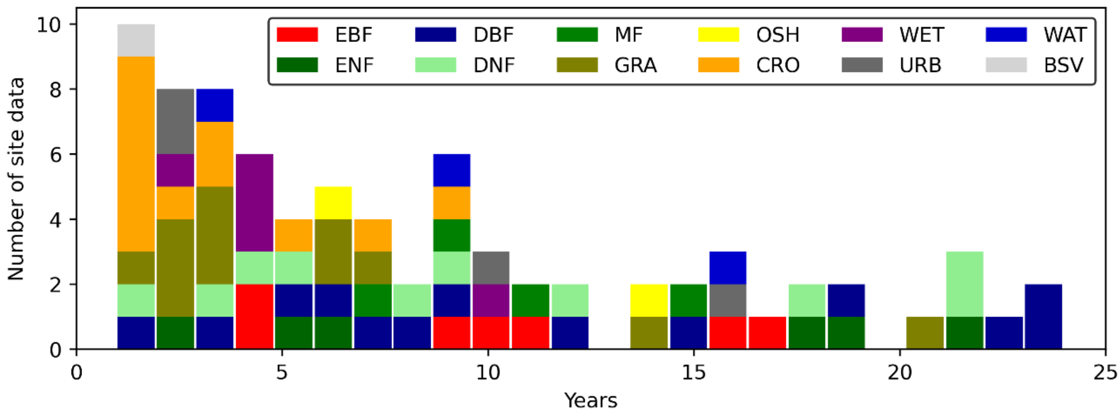

Fig. 4. The number of site records with different durations of data records. Sites affected by disturbance that changed the vegetation type during the observational period were classified according to the dominant land cover type: JP-Tse as DNF, JP-Tmk as DNF, and ID-Pbf as OSH. Land cover type abbreviations are as in Fig. 3.

2.2 Gap-filling meteorological variables

As with the FLUXNET2015 dataset (Pastorello et al., 2020; Vuichard and Papale, 2015), the meteorological variables were filled using the European Center for Medium-Range Weather Forecasts Reanalysis v5 (ERA5) data (Hersbach et al., 2020). Instead of using ERA5, we used the gap-filled meteorology if the site teams had filled the gaps. If meteorological variables for multiple sensors or positions were available, these variables were prioritized and aggregated before filling the gaps with ERA5 data because measured variables were less biased than ERA5, even when measured at different locations within a site. Then, air temperature, relative humidity, wind speed, downward shortwave radiation, downward longwave radiation, precipitation, and barometric pressure were filled using ERA5 after correcting biases at each site each year. Linear regression for meteorological variables (except precipitation) between observations and ERA5 was determined and then applied to correct site-specific biases in ERA5 to fill the data gaps. Water vapor pressure was calculated from the relative humidity, and the gaps in relative humidity were filled using the calculated water vapor pressure. If all meteorological variables were missing in some years, the bias was corrected using a regression for the entire data record. For precipitation (denoting rainfall plus snowfall), we determined the ratio of the annual precipitation between observations and ERA5 during the period when observed precipitation were available, and then filled hourly or half-hourly precipitation after multiplying the ratio to ERA5-based precipitation. If only the rainfall was measured, the correction ratio was determined using liquid precipitation which was defined as precipitation when air temperature was greater than 0 °C.

2.3 Gap-filling and flux partitioning

Gap-filling and flux partitioning were conducted based on REddyProc (version 1.3.2; Wutzler et al., 2018). First, the friction velocity (u*) threshold was determined for the identified low-turbulence conditions during the nighttime using the moving-point method (Papale et al., 2006). The u* threshold was determined from the temperature sensitivity of nighttime net ecosystem exchange (NEE) by seasonal clustering, an approach that is widely used in the FLUXNET community. In this dataset, we determined the u* threshold each year to consider its potential shift over the years, which is termed as a Variable u* Threshold (VUT) in FLUXNET2015 (Pastorello et al., 2020). The u* threshold was determined with 100 bootstrap replicates, where reference (original data obtained without using a bootstrapped sample), the 5th, 50th, and 95th percentiles of the estimated u* threshold were used for subsequent data filtering, gap-filling, and flux partitioning. Here, the nighttime was defined as downward shortwave radiation < than 10 W m^{-2}, and was further confirmed using exact solar time at the site location. On the basis of the estimated u* threshold, nighttime fluxes were eliminated. For urban sites, the threshold was generally not used (e.g., Liu et al., 2012; Ueyama and Ando, 2016); thus, the u* filtering was not applied for highly urbanized sites (JP-Sac and JP-Kgh).

Gaps in sensible heat flux (H), latent heat flux (LE), and NEE were filled using marginal distribution sampling (MDS) based on REddyProc. In MDS, a look-up-table (LUT) with air temperature, downward shortwave radiation, and vapor pressure deficit (VPD) was created for a 7-day window. When data gaps could not be filled with this window, they were filled in the following order: (1) LUT was applied with a 14-day window, (2) the mean diurnal variation method (Falge et al., 2001) was applied with a 1- or 2-day window, and (3) LUT was applied with a 21-day window, which was increased with a 7-day step until 70-day window if not enough data points were available. H, LE, and NEE were filled with the four different u* thresholds (reference, 5th, 50th, and 90th percentiles values) using MDS. In addition to the fluxes, net radiation, soil temperature, ground heat flux, and photosynthetically photon flux density (PPFD) were also filled using MDS. In the data collected from the site teams, energy imbalance correction (Twine et al., 2000) was not applied for H and LE at any sites; thus, the gap-filled H and LE were not corrected for the energy balance closure.

Using REddyProc, NEE was partitioned into gross primary productivity (GPP) and ecosystem respiration (RECO) using two methods: nighttime flux partitioning and daytime flux partitioning. In the nighttime partitioning method, nighttime NEE was parameterized on the basis of the temperature response function (Lloyd and Taylor, 1994) with a 7-day window, and then this function was used to calculate daytime and nighttime RECO. GPP was determined by subtracting RECO from NEE. In the daytime partitioning method (Lasslop et al., 2010), the common rectangular hyperbolic light-response curve was determined with a 4-day window, where the function accounted for the VPD effect on the initial slope of the light-response curve and the temperature effect of respiration. Calculation of GPP and RECO by the daytime partitioning method was based on the parameterized model, which did not directly use observed NEE. Using the two methods, fluxes were partitioned for NEE with different u* thresholds.

2.4 Site-specific considerations

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For the sites with heterogeneous land surfaces─JP-Khw and JP-Izm— the dominant land surface fluxes were extracted using wind sectors. JP-Khw is an evergreen needleleaf plantation forest consisting of *Cryptomeria japonica* (sugi) and *Chamaecyparis obtusa* (hinoki), but evergreen or deciduous broadleaf trees grow in gaps in some wind sectors. The H, LE, and CO_2 fluxes for sugi, which occupies the dominant wind sector area (the right-bank side), were extracted as "_QC". To extract these flux data, daytime fluxes for a wind sector on the right bank were selected, but nighttime fluxes for all wind sectors were used to increase data availability. Gap-filling and flux partitioning were done only for the extracted data. JP-Izm is located at the edge of an urban park; thus, measured flux representing this park (Ueyama and Ando, 2016) were selected and designated "_QC" in addition to the variables for measured fluxes representing both sectors of the urban park and other land covers. Gap-filling and flux partitioning were done only for the extracted data, which represented the urban park. These extracted flux data ("_QC") were included in the FULLSET files (described in section 2.5) in addition to measured fluxes for all sectors, and the gap-filled extracted fluxes were included in the SUBSET files (described in section 2.5).

Flux partitioning and gap-filling for JP-Nkm, located on a complex mountainous terrain, were conducted using slope-corrected shortwave radiation instead of downward shortwave radiation. Horizontally observed incident shortwave radiation was converted to radiation normal to the slope on the basis of the tilt and azimuth angles of the slope and the solar altitude and azimuth angles (Hammerle et al., 2007; Nie et al., 1992) as follows. Horizontally observed incident shortwave radiation was partitioned into direct and diffuse components using observed diffuse fraction (BF5, Delta-T Devices, UK), and the direct component was converted to that normal to the slope surface. The diffuse component was assumed to be isotropic. The total incident shortwave radiation normal to the slope surface was calculated as the sum of the direct component converted as above and the original diffuse component. When diffuse fraction was not observed, it was estimated from the relationship between the diffuse fraction and cloudiness; the latter was defined as the ratio of observed incident shortwave radiation to extraterrestrial radiation (Wang et al., 2018). The slope-corrected shortwave radiation was included as a variable, SW_IN_SLOPE_PI_1_1_1, in FULLSET.

For tropical ecosystems (TH-Kms, TH-Kmw, TH-Mmp, ML-Lhp, ID-Pbf), nighttime-based flux partitioning failed because little seasonality in temperature hampered the determination of a significant relationship between nighttime CO_2 flux and temperature. For these sites, only daytime partitioning was provided in the dataset. In a subtropical forest (KH-Kpt), the determination of the u* threshold failed; thus, the u* threshold was estimated using gap-filled u* by the site team instead of measured u* with data gaps. Since the data quality of u* for KH-Kpt seemed reasonable, we were unable to find out why REddyProc failed to determine the u* thresholds with measured u* in KH-Kpt. The u* threshold for ID-Puf and ID-Pdf could not be determined for several years; so, constant u* thresholds across these years were determined with REddyProc and applied for the subsequent data processing.

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Low availability of nighttime data due to the limited fetch in JP-Ako (Kosugi et al., 2005) hampered determination of the u* threshold, gap-filling flux, and flux partitioning with REddyProc. Consequently, no aggregated fluxes longer than half-hourly data were provided in the dataset.

Fluxes were not partitioned for lakes and a pond (JP-Swl, JP-Ksl, JP-Nap) and an urban center (JP-Sac). For the lakes and pond, gap-filling H, LE, and CO_2 flux was based on MDS. For JP-Sac, gap-filling for H and LE was also based on MDS, but MDS was not applied to CO_2 flux because it was controlled by traffic volume and air temperature (Ueyama and Takano, 2022). Gap-filling for CO_2 flux at JP-Sac was conducted by the site team on the basis of random forest regression (Ueyama and Takano, 2022), and was included as FCO2_F_PI in SUBSET and FULLSET. The u* threshold was not applied for JP-Nap, because the moving point method (Papale et al., 2006) developed for terrestrial ecosystems was not applicable to the pond.

In this dataset, CH_4 fluxes were not gap-filled, because (1) consistent gap-filling was not possible because of missing important variables, such as water table depth, and (2) inconsistent processes control CH_4 emissions on different land surfaces, such as rice paddies (JP-Hrt, TH-Kms), bog (JP-Bby; Ueyama et al., 2020c, 2022b), lake (JP-Swl; Iwata et al., 2018), pond (JP-Nap), and urban landscapes (JP-Sac, JP-Om1; Takano and Ueyama, 2021). If the gap-filled CH_4 fluxes were provided by the site team (i.e., JP-Bby), the data were included as FCH4_F_PI in SUBSET; otherwise, non-gap-filled data were included in FULLSET.

2.5 Data format

The dataset was prepared in a format compatible with FLUXNET2015 (Pastorello et al., 2020), which consists of files separated by sites, temporal aggregation (i.e., half-hourly/hourly, daily, weekly, monthly, and annual), and data product, i.e., FULLSET and SUBSET, as described later. The separated files for FULLSET and SUBSET were combined into two zip files for each site.

The following file naming rules (Pastorello et al., 2020) were followed.

[SITE_ID]_JapanFlux2024_[DATA_PRODUCT]_[RESOLUTION]_[FIRST_YEAR]_[LAST_YEAR]_[SITE_VERSION]-[CODE_VERSION].csv

[SITE_ID] is the site ID, the CC-SSS format: CC is a two-letter country code, and SSS is the three-character site code. [Data_PRODUCT] represents the data types: FULLSET, SUBSET, AUXMETEO, AUXNEE, or ERA5. SUBSET is the data type representing selected data variables, including basic micrometeorological data and fluxes, and quality information flags.

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FULLSET is a data file representing all variables of data products, including variables listed in SUBSET, original data before the processing pipeline, and internal variables. AUXMETEO includes auxiliary variables related to the meteorological downscaling of ERA5. ERA5 includes the meteorological data from ERA5 for 1990−2024. [RESOLUTION] is the temporal resolution of the data products: HH (half-hourly time step), HR (hourly time step), DD (daily time step), WW (weekly time step), MM (monthly time step), and YY (annual time step). [FIRST_YEAR] is the first year in the file, and [LAST_YEAR] is the last year in the file. The first and last years are based on the years in which the micrometeorological measurements are conducted, except for ERA5, where the first year is 1990 and the last year is 2024 for all sites. [SITE_VERSION] is the version of the original dataset, and [CODE_VERSION] is the code of the data processing pipeline used to process the dataset.

The SUBSET file included variables for basic meteorology and turbulent fluxes. The gap-filled meteorological variables of air temperature, incoming shortwave radiation, incoming longwave radiation, relative humidity, atmospheric pressure, precipitation, wind speed, net radiation, ground heat flux, soil temperature, and PPFD were included. If the original data provided by a site team included CO_2 concentration, soil water content, or wind direction, non-gap-filled data for these variables were included. A quality information flag was provided for gap-filled variables, where 0 is the original data, 1 is a gap-filled value of the most reliable quality, 2 is a gap-filled value of the medium quality, and 3 is the gap-filled value of the least reliable quality (Wutzler et al., 2018). If gap-filled CH_4 flux data were provided by the site team (i.e., at JP-Bby), they were included in SUBSET. The SUBSET file was provided with five temporal resolutions (half-hourly/hourly, daily, weekly, monthly, and annual aggregations).

The FULLSET file includes original unprocessed data, internal variables (aggregated meteorological variables measured at different locations or with different sensors), and meteorological data from ERA5, in addition to processed variables included in SUBSET. The FULLSET file is provided with the five temporal resolutions listed above.

For NEE, GPP, and RECO, the unit was μmol m^{-2} s^{-1} for half-hourly and hourly timescales, g C m^{-2} d^{-1} for the daily, weekly, and monthly timescales, and g C m^{-2} yr^{-1} for the annual timescale. For CH_4 flux, the unit for the half-hourly and hourly timescales was nmol m^{-2} s^{-1}, whereas the units for the other timescales were as the same as those for CO_2 fluxes. The units of precipitation were mm for the half-hourly and hourly timescales, mm d^{-1} for the daily, weekly, and monthly timescales, and mm yr^{-1} for the annual timescale. The units of other variables followed FLUXNET format (https://ameriflux.lbl.gov/data/aboutdata/data-variables/), which did not change with the timescales.

The ERA5 file contains the data for air temperature (TA_ERA5; °C), relative humidity (RH_ERA5; %), VPD (VPD_ERA5; hPa), vapor pressure (e_ERA5; hPa), saturation vapor pressure (e_sat_ERA5; hPa), wind speed (WS_ERA5; m s^{-1}), atmospheric pressure (PA_ERA5; kPa), incoming shortwave radiation (SW_ERA5; W m^{-2}), incoming longwave radiation

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(LW_ERA5; W m^{-2}), and precipitation (P_ERA5; mm). The ERA5 file is provided with the five temporal resolutions listed above. The variables in the ERA5 file were not corrected for the bias in comparison to the site data.

Two auxiliary files—for meteorology and u*-threshold—are provided. The AUXMETEO file includes the following statistics for downscaling ERA5 to the site scale: the linear slope between the measured data and ERA5 (ERA_SLOPE), intercept (ERA_INTERCEPT), root mean square error (ERA_RMSE), and correlation coefficient (ERA_CORRELATION). These statistics are included for each year and for all years when measurements were conducted. The TIMESTAMP column in the AUXMETEO file represents the year for the statistics, where -9999 represents the statistics for the entire year. The AUXNEE file includes the u* threshold in each year, with the reference threshold and the 5th, 50th, and 95th percentiles of the estimated u* threshold.

The dataset also includes the BADM files, which are used in the FLUXNET community. Six BADM files are provided: (1) general information, (2) instrument, (3) instrument operations, (4) vegetation cover, (5) soil, and (6) disturbance and management.

3 Database summary

3.1 CO_2 flux

Based on the dataset constructed, mean seasonalities in NEE, GPP, and RECO were as expected from the biomes and mean climatology (Figs. 5, 6). In northern boreal forests in Siberia (RU-Tur, RU-Nel, RU-Spl, RU-Spp), the magnitude of the flux was generally low, and growing seasons when GPP was not negligible were short. In the southern Eurasian boreal forests in Siberia and Mongolia (RU-Elg, MN-Udl, MN-Skt), the magnitudes of CO_2 fluxes were greater than those in the above northern boreal forests. Inland grasslands in Mongolia (MN-Nlk, MN-Hst, MN-Kbu) had smaller CO_2 flux magnitudes than the nearby forests (MN-Udl, MN-Skt). For temperate forest and grassland sites, the dataset showed known seasonality with spring onset, summer peak, and autumn senescence with low fluxes in winter. Among forest sites, seasonal variations became smaller in the subtropics (JP-Ynf), and clear seasonality disappeared in the tropics (KH-Kpt, MY-Lhp, ID, Pdf, ID-Puf, ID-Pbf) as the climate became warmer. Among rice paddies, single-cropping sites had a single peak (JP-Mse, JP-Hc2), but a double cropping site had two peaks (JP-Hc3) in GPP, RECO, and NEE (Fig. 6). For lakes (JP-Swl, JP-Ksl), a pond (JP-Nap), and an urban center (JP-Sac), CO_2 fluxes showed smaller seasonality than those at vegetation surfaces.

Some data for CO_2 fluxes raise suspicions. First, markedly negative NEE values in harsh winters were estimated for MN-Skt and MN-Kbu (Figs. 5, 6), which could be caused by an artifact known for the open path sensor (Burba et al., 2008). The artificially negative NEE caused a considerable positive GPP in winter. This, data users should be cautious about the data for MN-Skt and MN-Kbu. Second, the daytime partitioning method extrapolated the relationship obtained during the growing

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season to winters when NEE was not measured. The result was erroneous estimation of GPP and RECO (e.g., JP-Nkm in Fig. 5). Using the nighttime approach, GPP and RECO were not estimated for the period when NEE was not measured. Despite these suspicious data, the fluxes partitioned using the nighttime and daytime methods were generally consistent across the sites.

The spatial variabilities in annual NEE, GPP, and RECO were also consistent with earlier reports for Asian ecosystems (Fig. 7; Table 2). In Asia, the spatial variabilities in GPP and RECO are explained mostly by mean annual air temperature (Hirata et al., 2008; Kato and Tang, 2008; Saigusa et al., 2013; Yu et al., 2013). Except in disturbed forests and croplands, GPP and RECO increased linearly with mean annual air temperature (Fig. 7). Correlations of GPP and RECO with the annual sum of precipitation were lower than with mean annual air temperature. No clear correlation was found between annual NEE and mean annual air temperature or annual sum of precipitation, but the maximum CO_2 sink (i.e., negative NEE) with each temperature range appeared to be increased by temperature up to the annual mean temperature of approximately 15°C. Except for disturbed forests and urban sites, most ecosystems were estimated to be a CO_2 sink of up to 1.0 kg C m^{-2} yr^{-1}.

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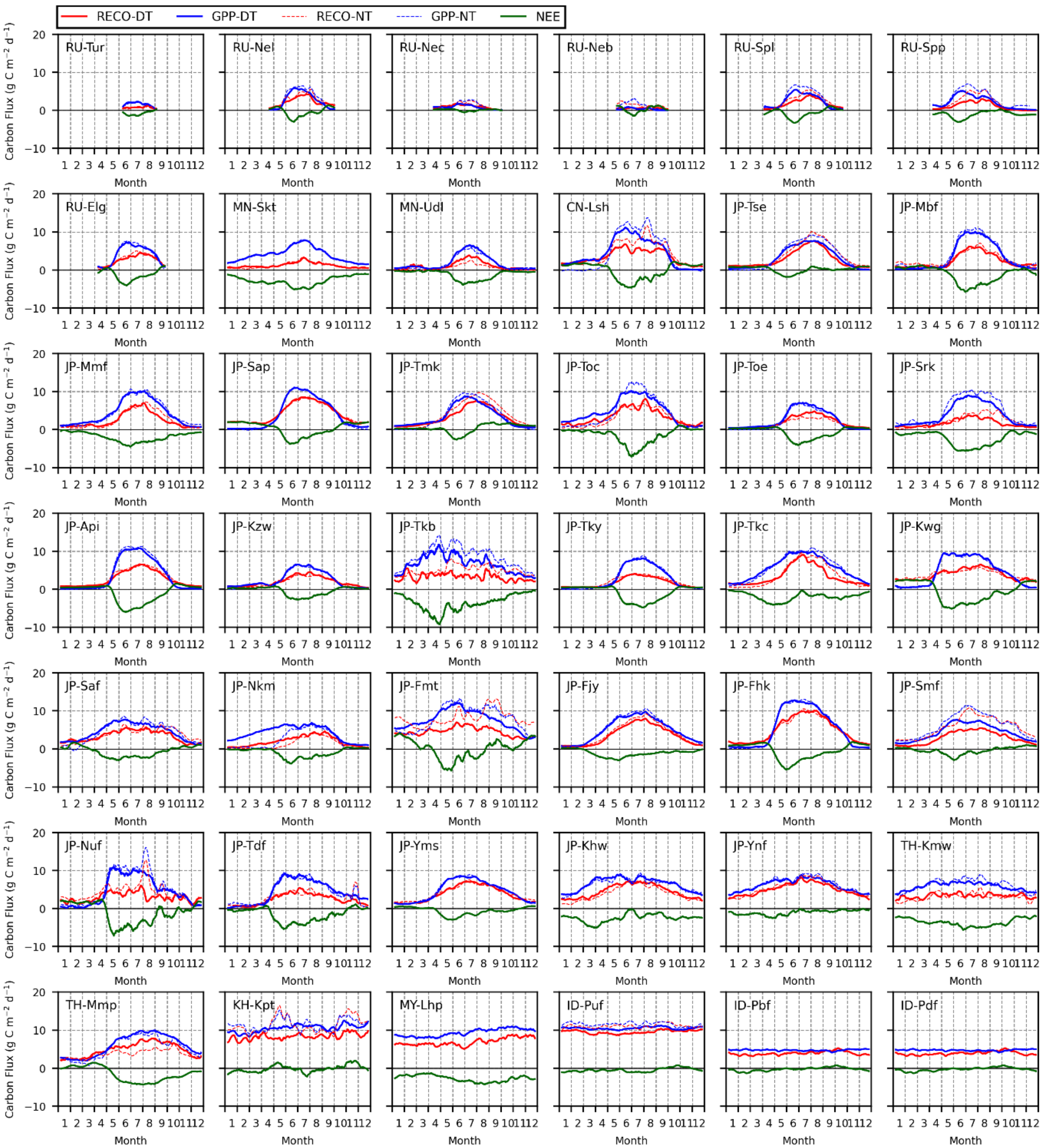

Figure 5. Mean seasonality of GPP, RECO, and NEE across forest sites. GPP and RECO were partitioned using the daytime method (DT, solid lines) or the nighttime method (NT, dashed lines). The seasonality is shown when NEE was measured, and those for GPP and RECO are shown when the partitioning was successful. The seasonality is the ensemble mean of the daily fluxes with for each day of year for all years. The sites are ordered according to latitude from high to low. The mean seasonality is shown for sites having the data at least one growing season.

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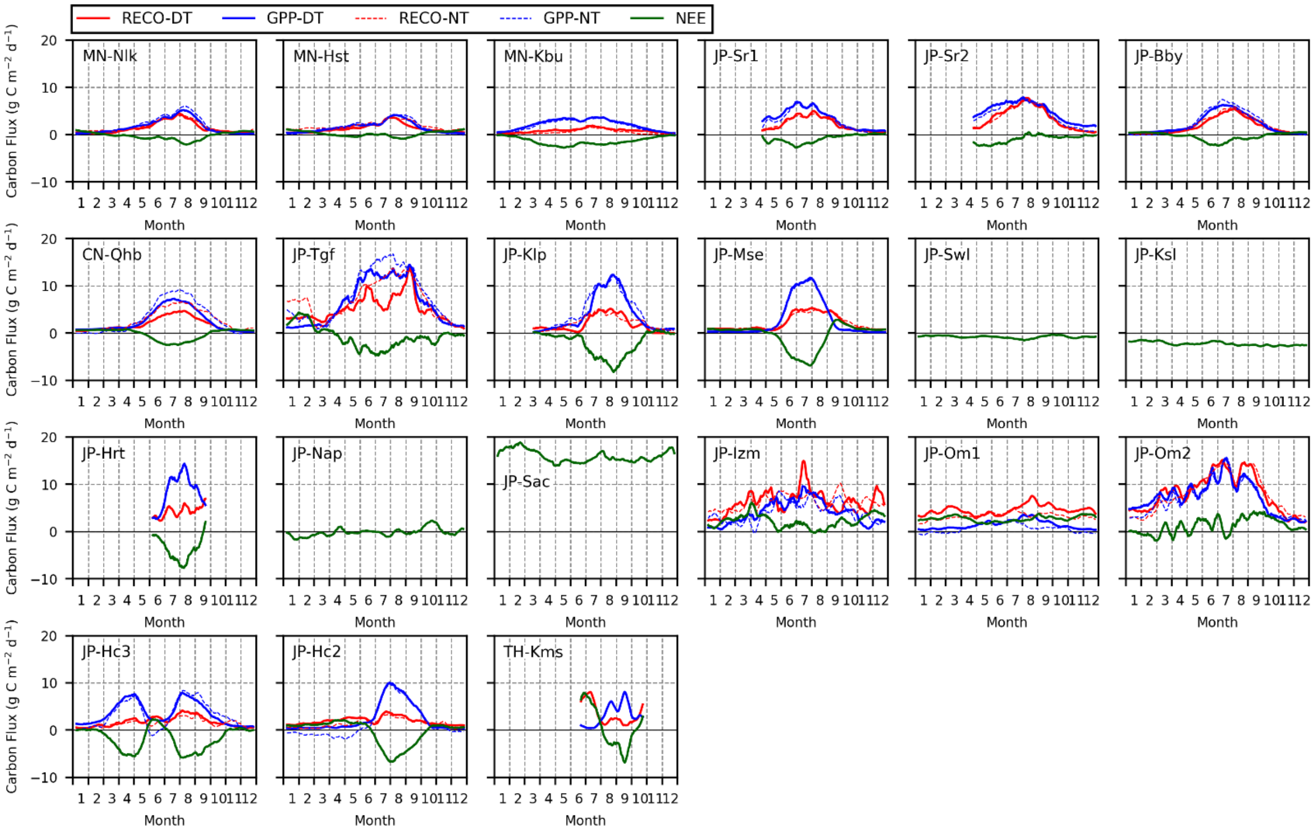

380 Figure 6. Mean seasonality of GPP, RECO, and NEE across sites other than forests. Designations are as in Fig. 5.

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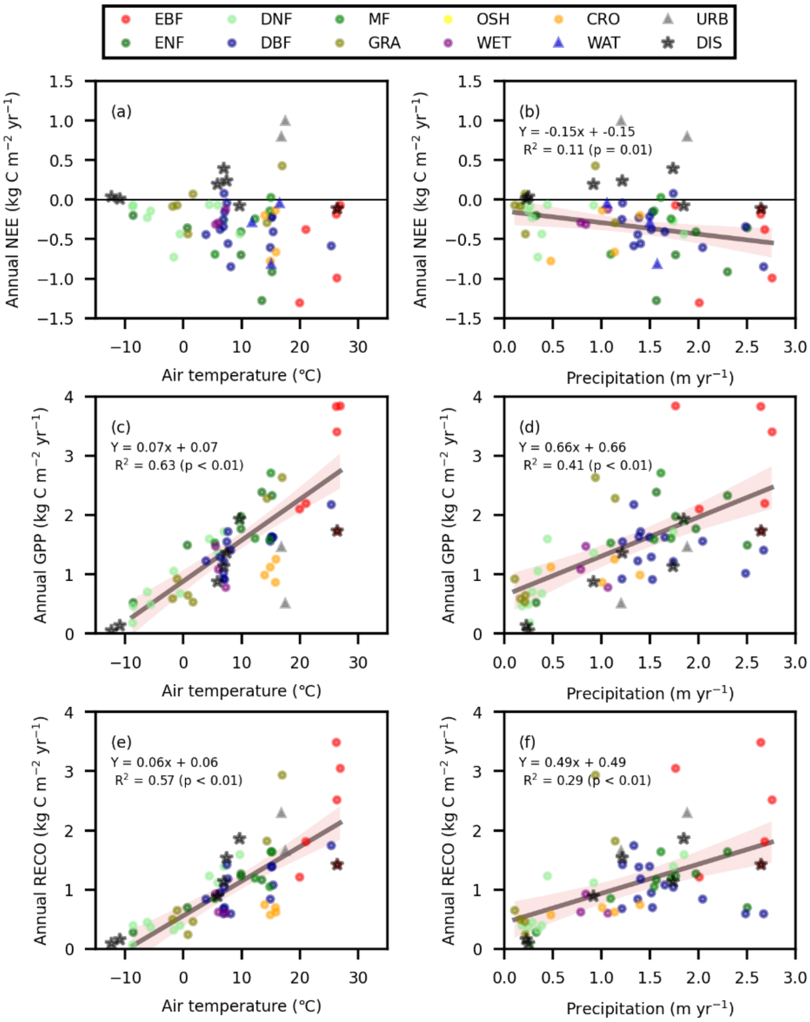

Fig. 7. Relationships of annual NEE (a, b), GPP (c, d), and RECO (e, f) to mean climate of annual mean air temperature (a, c, e) and annual sum of precipitation (b, d, f). GPP and RECO were estimated using the daytime method. The stars represent fluxes obtained at disturbed forests, where a disturbed forest was defined as a forest that experienced disturbance within the last 10 years. The annual fluxes were calculated based on the sum of mean seasonality shown in Figs. 5 and 6; missing measurements during the winter in high-latitudes were gap-filled as zero. Since sites of JP-Sap, JP-Tmk, and JP-Tse experienced significant disturbance (windthrow or clearcut) during the measurement period, data obtained within 10 years after a disturbance were classified as disturbed forests (DIS). The lines represent linear regressions with shading showing the confidence intervals ($p < 0.05$), that was determined excluding the DIS data. The annual CO_2 flux for JP-Sac (5.8 kg C m^{-2} yr^{-1}) is not shown due to the totally different carbon budget in the urban center compared to those in ecosystems. The values are shown in Table 2. Land cover type abbreviations are in Fig. 3.

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Table 2. Summary of mean annual air temperature (Tair), annual sum of precipitation (PREC), mean annual downward shortwave radiation (Rsd), mean annual carbon fluxes (NEE, GPP, RECO), and mean annual latent heat flux (LE), mean annual sensible heat flux (H), evapotranspiration (ET), and land cover. The statistics were calculated for observation years; for disturbed sites, the data were considered separately for the periods before, during, and after disturbance. Disturbed ecosystems were defined as those that experienced disturbance within the last 10 years. GPP, RECO, NEE, LE, and ET for boreal forests in Russia that lacked winter measurements (RU-Tur, RU-Neb, RU-Nec, RU-Nel, RU-Spl, RU-Elg, RU-Spp) were considered zero. GPP, RECO, and NEE at MN-Skt and MN-Kbu were also considered zero during winter to mitigate the influence of the negative values of CO_2 fluxes caused by an artifact associated with an open-path sensor.

Site ID	disturbance	Land cover	TAVE	PREC	SRAD	NEE	GPP	RECO	LE	H	ET
			℃	mm yr^{-1}	W m^{-2}	g C m^{-2} yr^{-1}	g C m^{-2} yr^{-1}	g C m^{-2} yr^{-1}	W m^{-2}	W m^{-2}	mm yr^{-1}
RU-Tur		DNF	-8.7	263	93	-81	183	80	N/A	N/A	N/A
RU-Neb	fire	GRA	-12.3	252	117	37	54	95	N/A	N/A	N/A
RU-Nel		DNF	-8.6	179	117	-70	465	396	8	N/A	100
RU-Nec	clearcut	OSH	-10.9	229	112	12	137	165	13	N/A	164
RU-Spl		DNF	-5.7	248	118	-139	494	368	21	N/A	272
RU-Spp		ENF	-8.7	328	117	-194	522	283	16	N/A	205
RU-Elg		DNF	-6.3	287	122	-225	707	460	21	N/A	264
MN-Skt		DNF	-1.7	346	169	-722	1059	324	16	41	202
MN-Udl		DNF	-0.6	384	157	-431	678	396	20	29	248
MN-Nlk		GRA	-1.9	162	171	-83	596	500	20	25	255
MN-Hst		GRA	1.6	211	181	76	540	468	19	23	239
MN-Kbu		GRA	0.7	214	183	-433	645	247	9	30	119
CN-Lsh		DNF	4.4	443	144	-60	1598	1235	28	28	353
JP-Sr1		WET	6.0	784	145	-288	1086	623	N/A	N/A	N/A
JP-Sr2		WET	5.5	838	140	-313	1476	936	N/A	N/A	N/A
JP-Tse	before	MIX	5.9	919	125	-26	1230	1027	21	8	263
	clearcut	GRA	5.9	919	125	192	877	889	19	5	236
	after	DNF	5.9	919	125	-71	1363	1120	29	6	365

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JP-Mbf		DBF	3.9	1373	134	-442	1227	847	42	19	526
JP-Mmf		MF	5.4	1092	134	-689	1537	860	46	17	568
JP-Bby		WET	7.2	1065	143	-118	786	612	42	10	534
JP-Sap	before	DBF	7.5	1215	145	-43	1553	1428	44	7	556
	windthow	DBF	7.5	1215	145	234	1364	1544	39	9	491
JP-Tmk	before	DNF	6.9	1737	138	-271	1724	1396	52	21	657
	windthow	GRA	6.9	1737	138	396	1138	1140	N/A	N/A	N/A
	after	DBF	6.9	1737	138	84	1222	1048	35	19	443
JP-Toc		DBF	7.6	1403	137	-556	1729	1189	35	28	446
JP-Toe		DBF	6.9	1207	128	-249	922	682	N/A	38	N/A
JP-Srk		DBF	8.1	2669	129	-847	1408	601	43	-2	535
JP-Api		DBF	6.3	1509	150	-375	1294	949	20	4	258
CN-Qhb		GRA	-1.1	108	200	-69	929	652	31	21	392
JP-Kzw		DBF	7.0	1524	165	-155	915	706	15	30	195
JP-Tkb		ENF	13.4	1563	157	-1272	2388	1171	51	7	652
JP-Tky		DBF	6.8	2483	146	-342	1024	600	11	22	136
JP-Tkc		ENF	9.8	1760	148	-695	1985	1232	45	13	576
JP-Tgf		GRA	14.3	1141	153	-291	2286	1829	54	11	696
JP-Klp		CRO	14.9	479	155	-774	1127	576	N/A	N/A	N/A
JP-Mse		CRO	13.9	1393	154	-197	996	748	68	5	875
JP-Swl		WAT	11.8	1499	178	-287	N/A	N/A	82	18	1043
JP-Ksl		WAT	15.1	1575	163	-817	N/A	N/A	60	21	765
JP-Kwg		DBF	15.2	1492	151	-214	1631	1393	N/A	8	N/A
JP-Saf		MF	12.3	1713	167	-242	1607	1200	61	34	777
JP-Nkm		ENF	0.6	2496	165	-351	1493	704	37	-7	454
JP-Fmt		MF	15.0	1611	158	35	2713	1641	76	29	977
JP-Kgh	urbanization	URB	16.5	1400	149	N/A	N/A	N/A	27	41	344
JP-Fjy		ENF	9.9	1971	166	-402	1773	1276	42	17	530
JP-Fhk	before	DNF	9.6	1846	168	-433	1907	1601	44	32	554
	thinnin	DNF	9.6	1846	168	-74	1936	1865	46	40	584

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	g										
JP-Smf		MF	14.8	1542	165	-142	1587	1059	57	13	734
JP-Nuf		DBF	15.4	1650	156	-406	1628	1080	78	6	1006
JP-Tdf		DBF	14.8	2039	155	-601	1558	848	52	9	662
JP-Yms		DBF	15.0	1386	159	-223	1637	1387	70	21	905
JP-Nap		WAT	16.5	1057	176	-49	N/A	N/A	60	9	773
JP-Sac	urbanization	URB	16.4	1594	158	5807	N/A	N/A	28	43	354
JP-Izm	urbanization	URB	16.8	1884	151	793	1461	2290	57	21	728
JP-Om1	urbanization	URB	17.5	1203	165	990	511	1654	25	38	322
JP-Om2	mowing	GRA	16.9	935	166	430	2634	2938	74	6	945
JP-Hc3		CRO	15.8	1136	175	-663	1255	624	52	9	663
JP-Hc2		CRO	15.7	1003	161	-132	871	699	64	7	817
JP-Khw		ENF	15.2	2294	158	-908	2337	1641	91	10	1174
JP-Ynf		EBF	20.9	2678	159	-374	2203	1814	70	1	906
TH-Kmw		EBF	19.9	2004	183	-1301	2107	1212	75	22	959
TH-Mmp		DBF	25.3	1333	205	-579	2177	1754	70	35	902
KH-Kpt		EBF	26.9	1761	206	-72	3843	3047	117	16	1515
MY-Lhp		EBF	26.2	2752	184	-989	3407	2524	93	22	1198
ID-Puf		EBF	26.1	2639	200	-183	3839	3484	116	27	1495
ID-Pbf	fire	OSH	26.4	2642	197	-110	1730	1426	91	26	1173
ID-Pdf		EBF	26.4	2642	197	-110	1730	1426	91	26	1173

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In the developed dataset, annual CO_2 fluxes tended to differ by land cover type (Fig. 8). Forest ecosystems included in the datasets had, on average, similar CO_2 sinks. Among the forest ecosystems, the mean CO_2 sink tended to be highest in ENF. Since grasslands in the dataset included a site that is frequently mowed (JP-Om2), the boxplot in grasslands (GRA) extended toward the annual emissions. Disturbed forests, on average, acted as a small CO_2 source. CO_2 emissions in urban centers (JP-Sac; 5.8 kg C m^{-2} yr^{-1}; not included in Fig. 8a) were considerably higher than those from natural or agricultural ecosystems. The annual GPP was highest in EBF among forest ecosystems, followed by ENF, DBF, and DNF. RECO was highest in EBF, whereas those in ENF, DBF, and DNF were similar to each other. Annual GPP and RECO varied greatly among grasslands because they included inland dry grasslands and Japan's weedy grasslands (Fig. 8b, c).

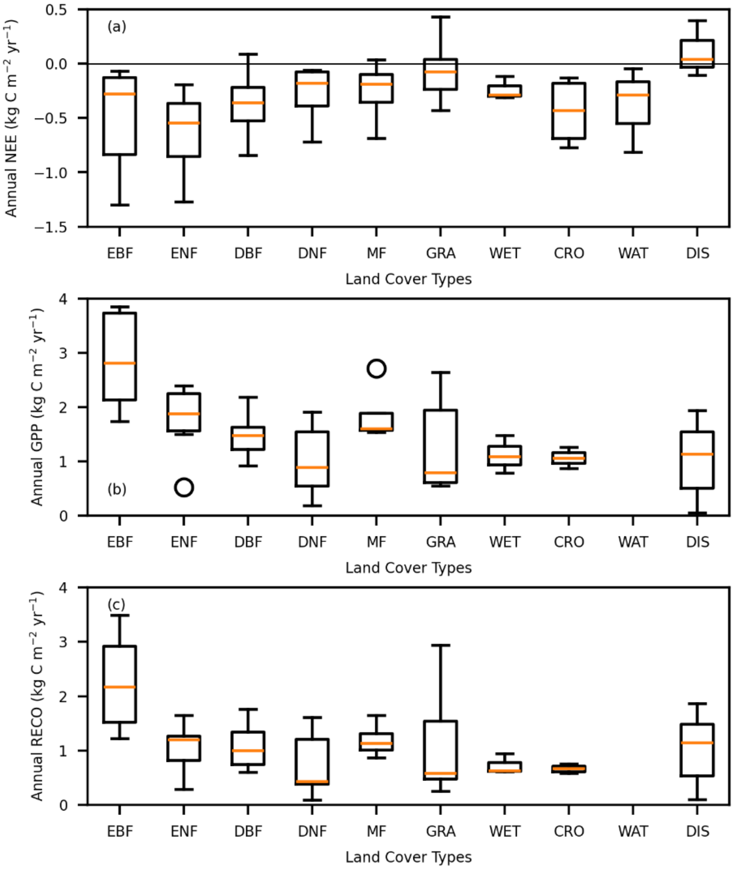

Figure 8. Boxplots for annual NEE, GPP, and RECO by land cover type. GPP and RECO were estimated using the daytime method. Fluxes at urban sites are not shown because the range of urban CO_2 emissions was totally different from those for vegetation or lakes. Since flux partitioning was not conducted for lakes, partitioned fluxes for lakes were not shown. Land cover type abbreviations are in Fig. 3. The definition of DIS was the same as in Fig. 7, where all data from RU-Nec, RU-Neb, and ID-Pbf are also classified as DIS.

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3.2 Energy fluxes

Mean annual energy fluxes represented in the dataset were explained better by air temperature than precipitation (Fig. 9; Table 2). The mean annual LE increased with the mean annual air temperature; their strong linear correlation could be explained by a close coupling between transpiration and photosynthesis (Medlyn et al., 2011), where spatial variations in annual GPP were strongly correlated with annual air temperature (Fig. 7c). The dataset included mostly ecosystems around the Pacific Ocean, which were especially densely distributed in Japan, whereas water-limited inland ecosystems were scarce. Consequently, the correlation between LE and precipitation was weaker than those reported in a literature survey for Asia (Kang and Cho, 2021). Under similar climate conditions, LE was lower and H was higher in urban landscapes in comparison with vegetation surfaces, in agreement with a previous report (Ueyama et al., 2021). Mean annual H did not change with air temperature or precipitation, possibly be caused by missing high-latitude observations owing to missing winter data (e.g., RU-Tur, RU-Spl, Ru-Elg) (Fig. 5). Negative H values in high-latitude ecosystems were observed owing to decreased available energy associated with snow albedo (Nakai et al., 2013; Ueyama et al., 2020b).

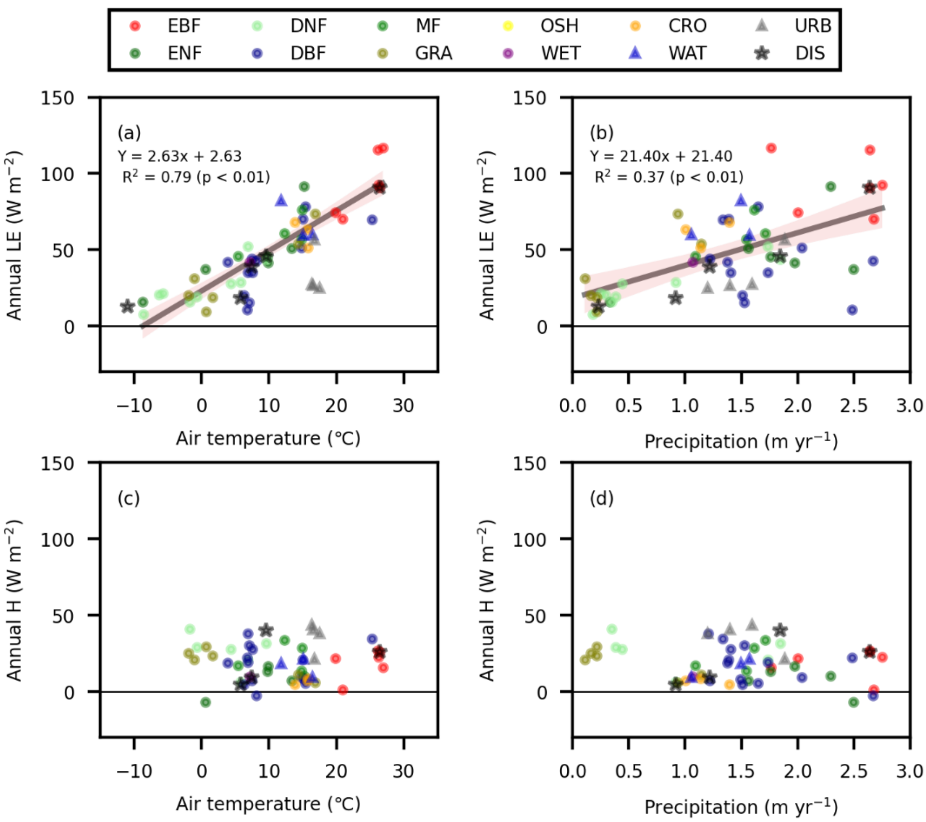

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Figure 9. Relationships of annual energy fluxes of latent heat flux (LE) (a, b) and sensible heat flux (H) (c, d) to mean climate of annual mean air temperature (a, c) and annual sum of precipitation (b, d). The classification of the disturbed forest (DIS) is as in Fig. 6. Annual H were only calculated for the case where there were no missing data in the mean seasonality, whereas the missing LE data during the winter were considered to be zero for boreal forests in Russia. The lines represent linear regressions, with shading showing the confidence intervals ($p < 0.05$), that was determined excluding the data from DIS, urban areas (URB), and lakes and ponds (WAT). The values are shown in Table 2. Land cover type abbreviations are in Fig. 3.

4 Data availability and data use guidelines

The dataset associated with this publication can be found at the ADS website (https://ads.nipr.ac.jp/japan-flux2024/), where individual site data have their own DOIs. All data are available under the CC BY 4.0 copyright policy with appropriate citations of this paper. We suggest that researchers planning to use this dataset as a core dataset for their analysis contact and collaborate with database developers and relevant site teams. As in the data policy of FLUXNET2015, in case of a synthesis using both CC BY 4.0 and other private data, all data should be treated as Tier Two of the FLUXNET data policy (data producers must have opportunities to collaborate and consult with data users).

5 Conclusions

The JapanFlux2024 dataset is the first public dataset that includes as much data as possible, both old and new, as an activity of JapanFlux. The dataset is consistent with previous synthesis studies in Asia in terms of seasonalities in CO_2 and energy fluxes across Japan and East Asia, but substantially increased the number of the data, 79 sites with 652 site-years from 1990 to 2023. The dataset will facilitate important studies in East Asia including Japan, such as those on land−atmosphere interactions, improvement of process models, and upscaling fluxes using machine learning. Since the dataset is compatible with the dataset provided by FLUXNET, the JapanFlux2024 dataset will bridge collaborations between researchers from Asia and FLUXNET.

Competing interests

The authors declare that they have no conflict of interest.

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