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► **To cite this version:**

Sébastien Gogo, Jean-baptiste Paroissien, Fatima Laggoun-Défarge, Jean-Marc Antoine, Léonard Bernard-jannin, et al.. The information system of the French Peatland Observation Service: Service National d’Observation Tourbières – a valuable tool to assess the impact of global changes on the hydrology and biogeochemistry of temperate peatlands through long term monitoring. *Hydrological Processes*, 2021, 35 (6), e14244, 8p. 10.1002/hyp.14244 . hal-03253867

HAL Id: hal-03253867

<https://hal.inrae.fr/hal-03253867>

Submitted on 28 Jun 2021

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The information system of the French Peatland Observation Service: Service National d'Observation Tourbières – A valuable tool to assess the impact of global changes on the hydrology and biogeochemistry of temperate peatlands through long term monitoring

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Abstract

Mitigating and adapting to global changes requires a better understanding of the response of the Biosphere to these environmental variations. Human disturbances and their effects act in the long term (decades to centuries) and consequently, a similar time frame is needed to fully understand the hydrological and biogeochemical functioning of a natural system. To this end, the 'Centre National de la Recherche Scientifique' (CNRS) promotes and certifies long-term monitoring tools called national observation services or 'Service National d'Observation' (SNO) in a large

range of hydrological and biogeochemical systems (e.g., cryosphere, catchments, aquifers). The SNO investigating peatlands, the SNO ‘Tourbières’, was certified in 2011 (<https://www.sno-tourbieres.cnrs.fr/>). Peatlands are mostly found in the high latitudes of the northern hemisphere and French peatlands are located in the southern part of this area. Thus, they are located in environmental conditions that will occur in northern peatlands in coming decades or centuries and can be considered as sentinels. The SNO Tourbières is composed of four peatlands: La Guette (lowland central France), Landemarais (lowland oceanic western France), Frasne (upland continental eastern France) and Bernadouze (upland southern France). Thirty target variables are monitored to study the hydrological and biogeochemical functioning of the sites. They are grouped into four datasets: hydrology, fluvial export of organic matter, greenhouse gas fluxes and meteorology/soil physics. The data from all sites follow a common processing chain from the sensors to the public repository. The raw data are stored on an FTP server. After operator or automatic processing, data are stored in a database, from which a web application extracts the data to make them available (<https://data-snot.cnrs.fr/data-access/>). Each year at least, an archive of each dataset is stored in Zenodo, with a digital object identifier (DOI) attribution (https://zenodo.org/communities/sno_tourbieres_data/).

KEYWORDS

data sharing, FAIR approach, peatland network, water and carbon cycle

1 | DATA BASE NAME

Information System of the French Peatland Observation Service, ‘Service National d’Observation Tourbières’.

2 | INTRODUCTION

There is a need for long-term observation to document and understand ecosystem responses to climate change and to stimulate synergies between observation and models. Responses of the water and the carbon (C) cycles of ecosystems to anthropogenic disturbances have to be addressed in a long-term time frame. However, long-term observation data are still scarce for many ecosystems. Peatlands are wetlands that cover only 3% of continental surfaces, but that contain between 17 and 27% of the world soil C stock (Jackson et al., 2017; Yu et al., 2010). Although peatlands function as a global C sink, they have switched locally to source systems (D’Angelo et al., 2021). This can have dramatic effects on climate change as a large amount of greenhouse gases (GHG) can be released into the atmosphere, thereby generating a positive feedback on temperature increase. Furthermore, the occurrence of peatlands within a catchment area influences the water fluxes and the export of organic carbon (OC) downstream, impacting the water quality (Fenner et al., 2011). Hence, long-term monitoring of water and C cycles in catchment areas containing such sentinel ecosystems is required. This is the rationale for the construction of the ‘Service National d’Observation (SNO) Tourbières’ (peatlands).The

implementation of long term monitoring systems requires the building of an efficient information system.

The SNO Tourbières, certified by the Centre National de la Recherche Scientifique (CNRS) in 2011, is composed of four French sites that are representative of mid-latitude lowland and upland peatlands (Figure 1). As the objectives are to document and understand how temperate peatlands will respond to local and global disturbances, 30 relevant target variables (Table 1) are monitored corresponding to 5 datasets: (a) water table depth (WTD); (b) multiparameter station; (c) soil-meteorological; (d) eddy covariance (EC) fluxes and (e) chamber fluxes. The target variables are monitored with the same protocol in each site (Table 1).

The datasets of the SNO Tourbières have been used to improve knowledge of hydrological processes. Binet et al. (2013) used WTD and the soil-meteorological datasets from the La Guette site to develop a model highlighting the sensitivity of evapotranspiration to peatland plant community composition. Bertrand et al. (2021) evaluated WTD to meteorological parameters and simulated future WTD under various IPCC scenarios. Bernard-Jannin et al. (2018) used the WTD dataset from La Guette to set up a model describing the dissolved organic C (DOC) concentration in peat water. They were able to identify the most relevant hydrological processes and factors determining DOC dynamics across a range of conditions at the same site. Rosset, Gandois, Le Roux, Teisserenc, Durantez Jimenez, Camboulive, and Binet (2019) and Rosset, Gandois, Le Roux, Teisserenc, Durantez Jimenez, Camboulive, and Binet (2019); Rosset, Gandois, Le Roux, Teisserenc, Durantez Jimenez, and Camboulive (2019); Rosset et al. (2020), with data from

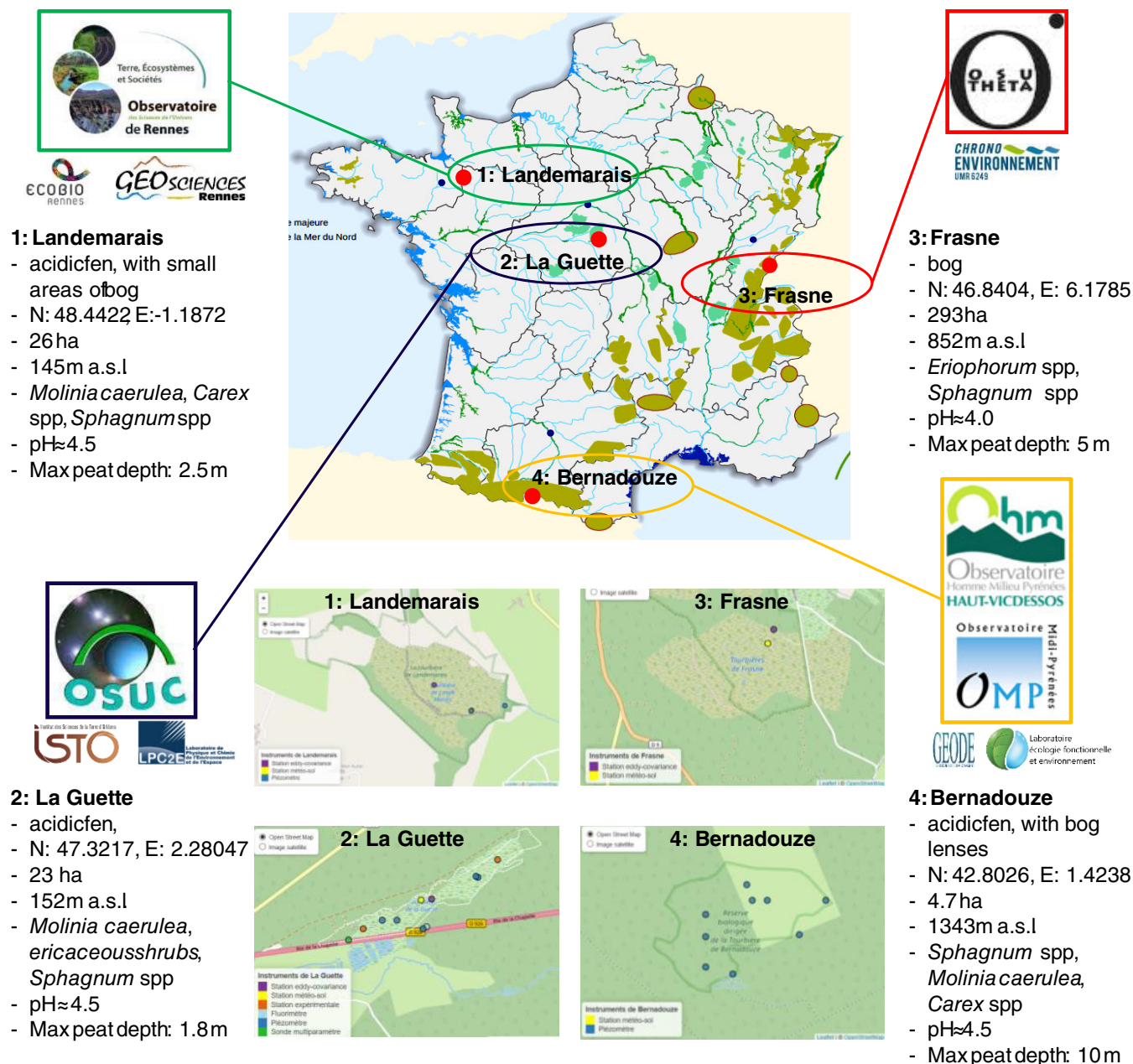


FIGURE 1 Locations and characteristics of the SNO Tourbières sites. Each site is associated to at least one observatory: Observatoire hommes-Milieux (OHM) and Observatoire Midi Pyrénées (OMP) for Bernadouze, Observatoire des sciences de l'Univers (OSU) THETA for Frasne, OSU de Rennes (OSUR) for Landemarais, OSU de la région Centre (OSUC) for La Guette. All the sites are registered in the dynamic ecological information management system - site and dataset registry (DEIMS-SDR): Bernadouze - <https://deims.org/708c9dcd-6757-4bb8-b849-3cc5666252f2>, Frasne - <https://deims.org/113183a6-38f2-4ec8-94ff-8bdbd4708ea4>, Landemarais - <https://deims.org/368383d9-d3a1-4abb-9ba3-d70bf071826e>, La Guette - <https://deims.org/331c1b2b-2283-4396-8e8b-d9d3d040e3cd> (map from: Institut Français de l'Environnement, Observatoire des Zones Humides, 2006)

the WTD and the multiparameter station (outflow rate and DOC concentration) datasets, investigated the factors influencing DOC and particulate organic carbon (POC) export. They were able to show that in a high-elevation peatland the majority of exported OC occurred in dissolved form during flood events. In the Critical Peat project, the WTD, multiparameter and EC flux datasets from Frasne were used to better understand the relationship between the underlying bedrock and the peatland water and C cycles (Lhosmot et al., 2019).

3 | SENSOR CHARACTERISTICS AND DATA ACQUISITION

An Orpheus Mini (OTT, pressure sensor) is used to measure the WTD in all sites (Table 1). The resolution of the sensor is 1 mm and its accuracy is 2 mm. It measures the water column pressure and the atmospheric pressure. The latter is subtracted from the former to obtain the water column height. Then the distance between the soil surface

TABLE 1 List of the target variables currently monitored in the SNO Tourbières sites, datasets and sensors

Target variables	Codes	Units	Datasets	Sensor model	Brand, city, country	Bernadouze	Frasne	Landemarais	La Guette
Atmospheric pressure	PA	hPa	Soil-meteorological	278	SETRA, Boxborough, MA, USA	x	x	x	x
Precipitation	P	mm	Soil-meteorological	ARG100	Campbell Sci, Logan-UT, USA	x	x	x	x
Photosynthetic photon flux density incoming	PPFD_IN	$\mu\text{mol m}^{-2} \text{s}^{-1}$	Soil-meteorological	SKP215	Skye Ltd, Llandrindod Wells, UK	x	x	x	x
Wind direction 2D	WD	°	Soil-meteorological	Windsonic	Gill, Lymington, UK	x	x	x	x
Wind speed 2D	WS	m s^{-1}	Soil-meteorological	Windsonic		x	x	x	x
Relative humidity	RH	%	Soil-meteorological	HMP155A	Vaisala, Vantaa, Finland	x	x	x	x
Air temperature	TA	°C	Soil-meteorological	HMP155A		x	x	x	x
Soil temperature	TS	°C	Soil-meteorological	T109	Campbell Sci, Logan-UT, USA	x	x	x	x
Soil water content	SWC	%	Soil-meteorological	CS650	Campbell Sci, Logan-UT, USA	x	x	x	x
Soil heat flux	G	W m^{-2}	Soil-meteorological	HFP015C	Huskeflux, Delft, Netherlands	x	x	x	x
Long-wave incoming radiation	LW_IN	W m^{-2}	Soil-meteorological	CNR4	Kipp & Zonen, Delft, Netherlands	x	x	x	x
Long-wave outgoing radiation	LW_OUT	W m^{-2}	Soil-meteorological	CNR4		x	x	x	x
Short-wave incoming radiation	SW_IN	W m^{-2}	Soil-meteorological	CNR4		x	x	x	x
Short-wave outgoing radiation	SW_OUT	W m^{-2}	Soil-meteorological	CNR4		x	x	x	x
Water table depth	WTD	m	Water table depth	Orpheus mini	OTT, Kempten, Deutschland	x	x	x	x
Water outflow rate	Q	l s^{-1}	Multiparameter station	EXO2	Campbell Sci, Logan-UT, USA	x	x	x	x
					YSI, Letchworth, UK				
Water temperature	TW	°C	Multiparameter station	Orpheus mini		x	x	x	x
pH	pH		Multiparameter station	EXO pH	YSI, Letchworth, UK	x	x	x	x
Conductivity	Cond	$\mu\text{S cm}^{-1}$	Multiparameter station	EXO Cond	YSI, Letchworth, UK	x	x	x	x
DOC export	FDOC	$\mu\text{mol org. C m}^{-2} \text{s}^{-1}$	Multiparameter station	EXO fDOM	YSI, Letchworth, UK	x	x	x	x
POC export	FPOC	$\mu\text{mol org. C m}^{-2} \text{s}^{-1}$	Multiparameter station	EXO Turbidity	YSI, Letchworth, UK	x	x	x	x
CO ₂ flux measurements, eddy-covariance	FC	$\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$	Eddy covariance fluxes	LI7200 + H550	LI-COR, Lincoln-NE, USA,	x	x	x	x
					Gill, Lymington, UK				
CH ₄ flux measurements, eddy-covariance	FCH4	$\mu\text{mol CH}_4 \text{ m}^{-2} \text{s}^{-1}$	Eddy covariance fluxes	LI700 + HS50		x	x	x	x
Sensible heat flux, eddy-covariance	H	W m^{-2}	Eddy covariance fluxes	LI7200 + HS50		x	x	x	x
Latent heat flux, eddy-covariance	LE	W m^{-2}	Eddy covariance fluxes	LI7200 + HS50		x	x	x	x
Actual evapotranspiration, eddy-covariance	ETR	mm/h	Eddy covariance fluxes	LI7200 + HS50		x	x	x	x
Ecosystem respiration, chamber	ERc	$\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$	Chamber fluxes	GMP343	Vaisala, Vantaa, Finland	x			
Gross primary production, chamber	GPPc	$\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$	Chamber fluxes	GMP343		x			
Net ecosystem exchange, chamber	NEEc	$\mu\text{mol CO}_2 \text{ m}^{-2} \text{s}^{-1}$	Chamber fluxes	GMP343		x			
Soil temperature, manual	TSm	°C	Chamber fluxes	SDEC probe	SDEC, Tauxigny, France	x			

and the top of the water column is measured manually to obtain the WTD. Since this value can vary due to soil moisture changes, and snow and ice compaction, this variable is seasonally measured after the installation of the sensor and averaged over the longest period possible. This average value is then used to calibrate the whole time series.

The same sensor is also used to assess the streamflow at the outlet of the catchment containing the peatlands. The outflow intensity is proportional to the water height. At low frequency, water outflow is measured using salt dilution and the water column height is simultaneously recorded. A calibration curve relating outflow and water height is established. This curve is used to produce a high frequency outflow time series (1 recording every 30 min).

Fluorescence of the dissolved organic matter (fDOM) is used as a proxy to assess the DOC concentration (Rosset, 2019a). A fraction of the total DOM fluoresces. It is assumed that the total DOC is proportional to the fraction of fluorescent DOM (Rosset, 2019a). A fluorimeter (EXO fDOM) is connected to the multiparameter station (EXO2, Table 1). This optical sensor measures fluorescence at the excitation/emission couple at 365/480 nm. EXO fDOM expresses the fluorescence in quinine sulphate units (QSU) in the range of 0–300 ppb QSU, at a resolution of 0.01 ppb QSU and with a detection limit at 0.07 ppb QSU. The fDOM is recorded once every 30 minutes. At low frequency (once a month), water is sampled and the DOC content is assessed with a total OC analyser (infrared analyser, detection limit: $4 \mu\text{g l}^{-1}$, measuring range $0.4 \mu\text{g l}^{-1}$ – 30 g l^{-1}). At the same time, the fDOM value is recorded. Then, a statistical relationship between fDOM and DOC is calculated. By applying the equation to the fDOM data, a DOC concentration time series can be estimated. Multiplying the DOC concentration by Q gives the DOC flux out of the peatland: FDOC.

The same principle is applied to assess POC export (FPOC), with turbidity instead of fluorescence. A turbidimeter (EXO Turbidity) is connected to the EXO2. This is an optical sensor measuring light diffusion of (near infrared, excitation at 860 nm) at an angle of 90° . EXO Turbidity expresses the turbidity in formazin nephelometric units (FNU) in the range of 0–4000 FNU and at a resolution of 0.1 FNU (precision of 5%; Rosset, 2019a). The turbidity is recorded once every 30 min. At low frequency (once a month and during flood events), water is sampled and the POC content is assessed by filtering the water ($0.7 \mu\text{m}$, glass fibre filter, GF/F, WHA1825047, Whatman), measuring the mass of suspended matter and the C content of the suspended matter on the filter (elemental analyser, precision of 0.2%, accuracy of 0.05%). At the same time, the turbidity value is recorded. Then, a statistical relationship between turbidity and POC is calculated. By applying the equation to the turbidity data, a POC concentration time series is obtained. Multiplying the POC concentration by Q gives the POC flux out of the peatland, FPOC.

The EC technique was chosen as it is the most appropriate tool to monitor evapotranspiration and surface-atmosphere C fluxes (carbon dioxide and methane) over a large surface of an ecosystem (Flechar et al., 2020). The EC and soil-meteorological measurements follow the recommendations of the Integrated Carbon Observation System (ICOS, <https://www.icos-cp.eu/>) for level 2 stations ([\[icos-cp.eu/icos/documents/instructions\]\(https://www.icos-cp.eu/icos/documents/instructions\)\). For carbon dioxide \(\$\text{CO}_2\$ \) and water vapour \(\$\text{H}_2\text{O}\$ \) the sensor used is the LI-COR enclosed LI7200 IRGA \(infrared gas analyser\). For \$\text{CO}_2\$, the calibration ranges from 0 to 3000 ppm, with an accuracy within 1% of the reading. For \$\text{H}_2\text{O}\$, the calibration ranges from 0 to 60 \$\text{mmol mol}^{-1}\$, with an accuracy within 2% of the reading. For the methane \(\$\text{CH}_4\$ \) concentration, the sensor model is the open-path LI7700 \(measurement based on wavelength modulation spectroscopy at ambient air temperature and pressure\). The calibration ranges from 0 to 40 ppm, with an accuracy within 1% of the reading. A GILL HS50 ultrasonic anemometer is used to obtain the 3D wind direction and speed. For the wind speed, the calibration ranges from 0 to \$45 \text{ m s}^{-1}\$, with an accuracy within 1% of the reading. For the wind direction, the directional resolution is \$1^\circ\$, with an accuracy within 1% of the reading. All the gas concentrations and the wind variables are recorded at 20 Hz. The surface exchange fluxes are calculated at a 30-minute time-step using Eddypro \(open source software from LI-COR\) and Rflux \(developpers\) software.](http://www.</p>
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The chamber flux data are collected manually at low frequency (6–12 times per year) with the Vaisala CARBOCAP GMP343 (measuring range: 0–2000 ppm, precision: $\pm 5 \text{ ppm} + 2\%$ of the value). The chamber is 30 cm high with a diameter of 30 cm, portable, and removed between measurements. The probe is inserted into the chamber and left between 2 and 5 min. Flux is calculated from the slope of the CO_2 concentration against time (D'Angelo et al., 2021).

4 | DATA FLOW

From acquisition to accessibility, the data of the SNO Tourbières go through four stages (Figure 2): (a) collection/storage; (b) processing; (c) integration into a database; (d) dissemination. The underlying principle of the SNO Tourbières information system is the findable, accessible, interoperable, re-usable (FAIR, Wilkinson et al., 2016) approach.

1. Collection and storage. The raw data (sensor output) are stored in the FTP server 'SRV-SO' located in CNRS – Orléans (SRV = server, SO = system of observation, Figure 2). Data produced by automated stations are acquired at different frequencies, from 20 Hz (EC) to 1 measurement per 30 min.
2. Processing. Each dataset undergoes a quality check and data treatment. Calculations of high frequency time series are undertaken with scripts that may require specific information, such as the relationship between water height and water flow rate at the outlet obtained manually and at a low frequency. All the information (metadata) and scripts are stored in a second file. The processed data are stored in a third file (CSV format) with a measurement frequency of 1 per 30 min frequency for all data sets. The data from this third file proceed to the next step (Figure 2).
3. Integration into the database. All the operators working on data processing can store their data in the database at: <https://data-snot.cnrs.fr>. Before uploading a data set, the operator must fill in the information required by the system to allow the data to be

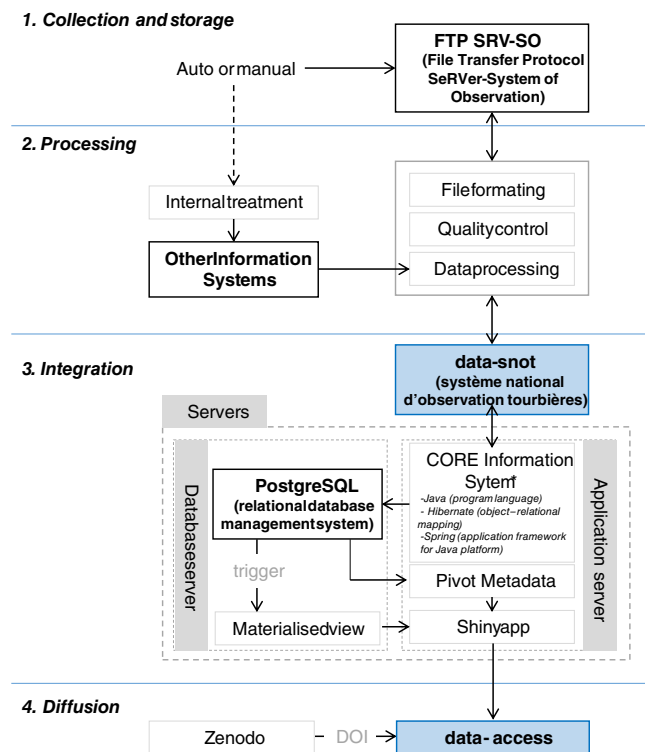


FIGURE 2 Data flow within the information system from the sensors to the public and the DOI attribution. The core information system used originated from the Service d'Observation d'Expérimentation au long term pour la recherche en environnement (SOERE, long term observation and experimental service for research on the environment)

uploaded to the database and to produce the metadata. This information is called 'reference data'. The core (database and web application) of the SNO Tourbières information system was adapted from the standard developed by the ECO-INFORMATIQUE team of the Institut National de la Recherche en Agriculture, Alimentation et environnement (INRAe, InfoSol unit in Orléans). The database management system used is PostgreSQL (<https://www.postgresql.org/>).

4. Dissemination. The data are made accessible through web applications managed by the SNO Tourbières team and through data portals managed by research infrastructures (Observatoire de la Zone Critique Applications et Recherche: OZCAR, ICOS, FLUXNET-CH4, see data availability section below).

5 | FUNDING, CONTRIBUTORS AND DATA OWNERSHIP

Recurring funding for the network coordination and some equipment is provided by the CNRS. The permanent staff cost is covered by the different universities and research institutes: CNRS, Universités d'Orléans, de Bourgogne Franche-Comté, de Rennes 1, Paul Sabatier

and Jean Jaurès, INRAe. Equipment, operating costs and non-permanent staff are funded through projects: (a) inter-regional European Union programme INTERREG: CARE-PEAT: Restoring the carbon storage capacity of peatlands (North West Europe, NWE 808), REPLIM: Red Pirenaica de Observatorios de ecosistemas vulnerables (lagos, turberas) al cambio climático (Program Of Cooperation España-France-Andorra, POCTEFA, EFA056/15), PIRAGUA (POCTEFA, EFA210/16), OPCC (Observatoire Pyrénéen des Changements Climatiques, POCTEFA, EFA082/15); (b) State-Region Planning Agreement (Contrat Plan Etat-Région - CPER) project; (c) Agence National de la Recherche, ANR, projects: PEATWARM (ANR-07-VUL-010), TRAM (ANR JCJC 15-CE01-008), Laboratoires d'Excellences, LabEx DRHIMM (Dispositif de Recherche Interdisciplinaire sur les Interactions Hommes-Milieux, 11-LABX-0010), LabEx VOLTAIRE (VOLatils - Terre, Atmosphère et Interactions - Ressources et Environnement, 10-LABX-0100) or the; (d) Region Centre-Val de Loire (PIVOTS: Plateformes d'Innovation, de Valorisation, d'Optimisation Technologiques environnementales, CARBioDiv: restoring peatlands to promote Carbon sequestration and BioDiversity, CarEx: Carbon sequestration through Experimentation on vegetation), Bourgogne Franche Comté (CRITICAL Peat).

S. Gogo, F. Laggoun-Déferge, G. Bertrand, A.-J. Francez, D. Galop, L. Gandois, D. Gilbert contributed as data producers and/or site managers and/or network coordinators. J.-B. Paroissien, L. Perdereau Y. Brossard, J.-P. Caudal, E. Lerigoleur contributed to the building and/or the technical set-up (in situ and/or in relation to the server) of the information system. J.-M. Antoine, L. Bernard-Jannin, P. Binet, S. Binet, G. Bouger, T. Camboulive, S. Chevrier, G. Chiapiuso, B. D'Angelo, P. Durantez, C. Fléchar, C. Guimbaud, L. Hinault, A. Jacotot, F. Le Moing, G. Le Roux, F. Leroy, A. Lhosmot, Q. Li, E. Machado Da Silva, J.-S. Moquet, J. Mora-Gomez, T. Rosset, M.-L. Toussaint participated in producing the datasets (maintenance, data retrieval, calculations, funding).

The data belong to the French State and can be used by anybody as long as the data are properly cited, either by acknowledging the SNO Tourbières and/or by citing their digital object identifier (DOI) when available. Unless otherwise stated, data from SNO-Tourbières are licensed under Creative Commons CC BY-SA 4.0.

6 | INVOLVEMENT OF THE SI SNO TOURBIÈRES IN NATIONAL AND INTERNATIONAL RESEARCH INFRASTRUCTURES

At the national level, the SNO Tourbières is part of OZCAR, the French research infrastructure (RI) on the critical zone (<https://www.ozcar-ri.org/>, Gaillardet et al., 2018), and is registered in the OZCAR information system, THEIA-OZCAR (<https://in-situ.theia-land.fr/>; Braud et al., 2020). The Bernadouze site is part of an interdisciplinary observatory Observatoire Hommes-Milieux (OHM - Laboratoire d'excellence Dispositif de Recherche Interdisciplinaire sur les Interactions Hommes-Milieux: LabEx DRIHM). Data collected in this

framework are available at: <http://193.55.175.137:8080/geonetwork/srv/fre/catalog.search#/home>. At the European level, La Guette peatland has been part of the French and European ICOS ecosystem network (<https://www.icos-cp.eu/>, Franz et al., 2018) as an associated site since November 2019. At the international level, the methane flux of La Guette peatland is part of the FLUXNET-CH4 dataset (Knox et al., 2019; Delwiche et al., in prep.).

7 | DATA AVAILABILITY

The data of the SNO Tourbières are available through a web application developed with R-Shiny: <https://data-snot.cnrs.fr/data-access/> (Figure 2). A tool to produce customized figures was developed by dreamRs, a company developing data science packages in R language (<https://www.dreamrs.fr/>). All the applications used in the SNO Tourbières information system are located in the CNRS servers in Orléans.

EC fluxes and soil-meteorological data of La Guette peatland are also available through the ICOS carbon portal: <https://www.icos-cp.eu/observations/carbon-portal>. The CH₄ fluxes of this site are available at: <https://fluxnet.org/doi/FLUXNET-CH4/FR-LGt> (<https://doi.org/10.18140/FLX/1669641>).

Attributing a DOI to a dataset ensures its correct citation and long lasting archiving. Each DOI is associated to a landing page that has to remain accessible in the long term. The strategy in the SNO Tourbières is to assign a fixed DOI to a dataset and apply a versioning to avoid too many landing pages. To do so, the chosen application is Zenodo (Figure 2), an open access data, research and software repository that generates a DOI and manages versioning. With the versioning, as soon as we have a new dataset, a new DOI is created with its associated metadata. This process makes the system flexible, traceable and manageable. The data are updated between one and three times per year. A SNO Tourbières data repository has been created: https://zenodo.org/communities/sno_tourbieres_data/. This application allows contribution from and to other data managing structures. An article can be written with a subset of data. These data can be deposited in another data repository with the reference to the article. The SNO Tourbières dataset will mention if it contains this particular sub-dataset: 'HasPart' (e.g., Rosset, 2019b; Rosset, Gandois, Le Roux, Teisserenc, Durantez Jimenez, Camboulive, & Binet, 2019). Furthermore, datasets of the SNO Tourbières can be contained in a larger data set (e.g., Fluxnet, ICOS, OZCAR) and will mention it as: 'IsPartOf'.

ACKNOWLEDGEMENTS

The SNO Tourbières team would like to thank A. Schellenberger and P. Tcherniatinsky from the ECO-INFORMATIQUE team of the INFO SOL laboratory of the INRAe center in Orléans for their help in adapting the initial database to our requirements. We also thank V. Chaffard and C. Coussot for helping us integrate our data in the OZCAR-THEIA information system. The SNO Tourbières is coordinated by the Observatoire des Sciences de l'Univers en region Centre (OSUC - Université d'Orléans, CNRS, CNES). The SNO Tourbières is

certified by the CNRS. The SNO Tourbières is part of the Research Infrastructure OZCAR (Observatoire de la Zone Critique, Application et Recherche) and one site, La Guette, is part of ICOS (Integrated Carbon Observation System) and another one, Bernadouze, is part the Observatoire Hommes-Milieux (OHM - Laboratoire d'excellence Dispositif de Recherche Interdisciplinaire sur les Interactions Hommes-Milieux: LabEx DRIIHM).

DATA AVAILABILITY STATEMENT

The data belong to the French State and as such can be used by anybody as long as the data are properly cited (either by acknowledging the SNO Tourbières and/or by citing their digital object identifier - DOI - when available). Unless otherwise stated, data from SNO Tourbières are licensed under Creative Commons CC BY-SA 4.0.

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How to cite this article: Gogo, S., Paroissien, J.-B., Laggoun-Défarage, F., Antoine, J.-M., Bernard-Jannin, L., Bertrand, G., Binet, P., Binet, S., Bouger, G., Brossard, Y., Camboulive, T., Caudal, J.-P., Chevrier, S., Chiapiuso, G., D'Angelo, B., Durantez, P., Flechard, C., Francez, A.-J., Galop, D., ... Toussaint, M.-L. (2021). The information system of the French Peatland Observation Service: Service National d'Observation Tourbières – A valuable tool to assess the impact of global changes on the hydrology and biogeochemistry of temperate peatlands through long term monitoring. *Hydrological Processes Part A*, 35(6), e14244. <https://doi.org/10.1002/hyp.14244>