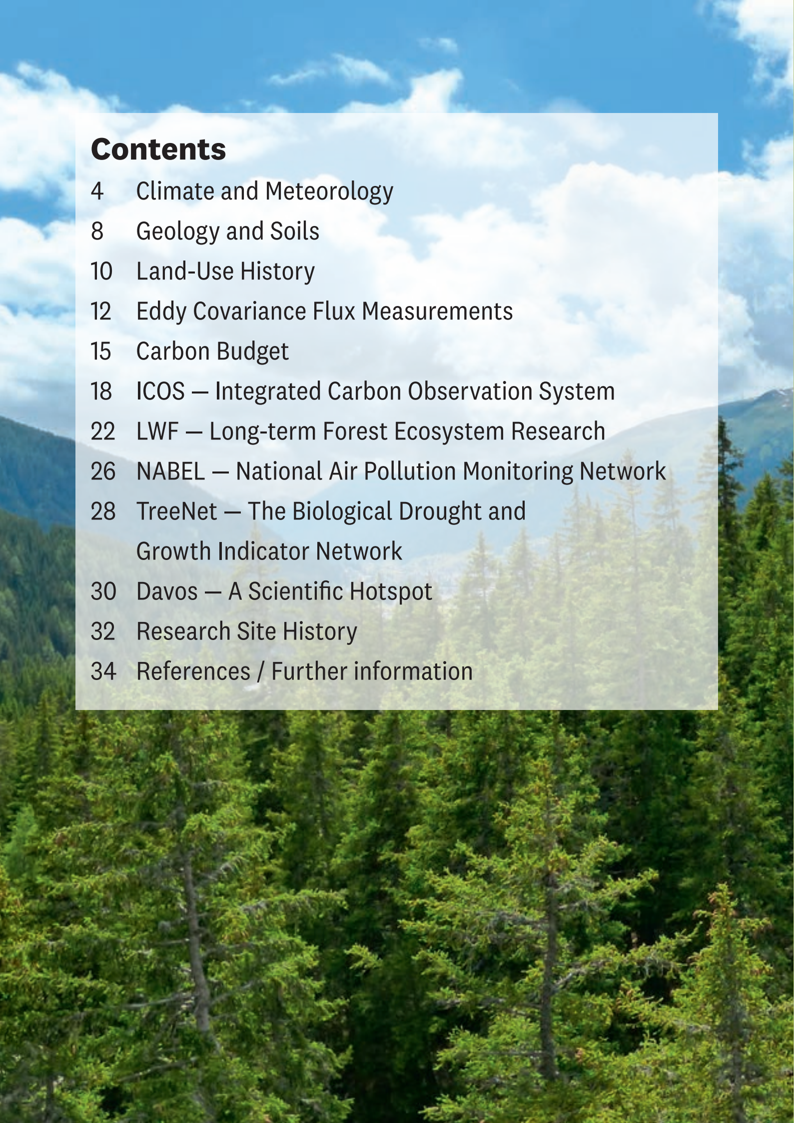
Long-Term Environmental Research

The Davos-Seehornwald Site

ICOS National Network Switzerland



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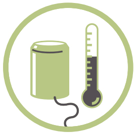
Welcome!

We cordially welcome you to the Davos-Seehornwald research site! It is located in the eastern part of Switzerland in a subalpine forest at 1639 m a.s.l. and mainly consists of Norway spruce trees, which are about 30 meters tall and up to 450 years old. Here, we investigate how air pollution and climate change affect forest health, growth and development as well as the forest's greenhouse gas budget. The first CO_2 flux measurements started already in 1995 and the site is one of the oldest ecosystem flux sites globally (continuous eddy covariance flux data since 1997). The owner of the site is the Federal Office for the Environment (FOEN). Today, it is used by the Swiss Federal Laboratories for Materials Science and Technology (Empa), ETH Zurich and the Swiss Federal Institute for Forest, Snow and Landscape Research (WSL) and is part of well-known national and international research networks. This joint effort of measurements allows Davos to be the only subalpine Class 1 forest site within the European Research Infrastructure ICOS (Integrated Carbon Observation System).

In this excursion guide, we give a brief overview of the station as well as its environmental surroundings and we present some interesting scientific observations from long-term research. Enjoy your stay with us!

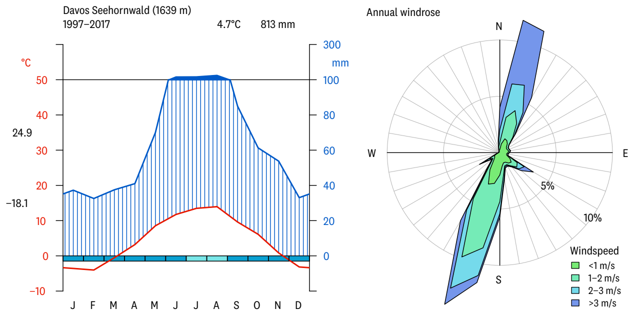
Climate and Meteorology

Davos has a cool temperate climate with a precipitation peak in summer during the growing season of the trees. In winter, there is typically a continuous snow cover from early November to late April, but in recent years the persistent snow cover occasionally only was observed from late December to late March. The annual precipitation measured at the site is 813 mm (1997-2017), a value that is substantially lower than at orographically more exposed localities in the Alps at comparable elevation.



But precipitation exceeds evapotranspiration losses by far in all months. Frost can occur in all months, but is not very frequent in July and August. Since there is no permafrost in the Alps at such elevations and exposures, a continuous snow cover in winter means that the soils do not freeze at depths, and decomposers remain active even during winter.

The wind directions are almost exclusively from NNE or SSW, a clear effect of channelling of the wind by the surrounding mountains. This is a typical feature in mountainous areas where up-valley winds dominate daytime conditions, whereas down-valley winds dominate at night. Direct cold-air drainage from the local north-exposed slope of the Seehorn peak is rarely observed, and in general the cold air accumulating in the

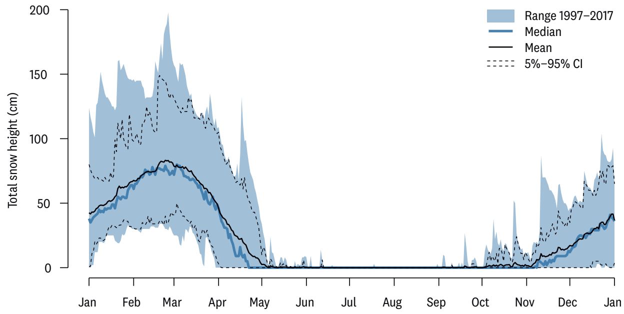


Climate diagram (left, numbers to the left of air temperature axis show max. and min. daily average air temperature of hottest and coldest month, respectively) and windrose (right), 1997–2017.

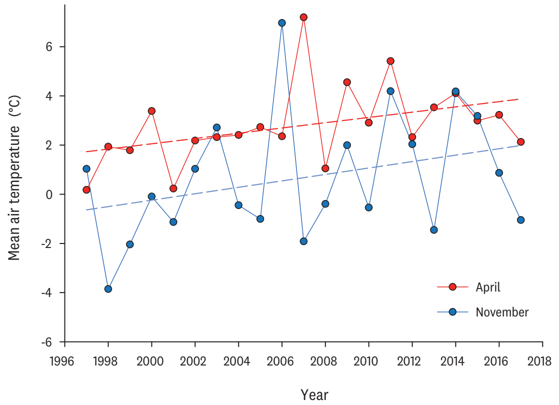
Cold air pools in the Davos valley (uppermost height where cold air can pool) and drains towards the east across the Wolfgang pass (red arrow). The Davos-Seehornwald site is in the center; direction of view is towards the east.

topographic basin of Lake Wolfgang acts like an aerodynamic surface linking the site directly with the Wolfgang pass at similar elevation, which defines the upper limit of the cold-air lake in winter and during nighttime. This pooling of cold air leads to the characteristic wind directions along the contour lines of the Seehorn mountain slope, and thus limits the up-slope and down-slope movements of air masses.

Climate change is expected to be more pronounced in mountainous regions than at global scale. Monthly mean air temperatures at the Davos Seehornwald site increased as shown for April and November air temperatures over the period since 1997 when continuous eddy covariance flux measurements were started. November air temperatures that were typically below freezing at the end of the last century are now frequently above 0°C. Instrumental air temperature records have been started in 1863 in the Davos area and thus are one of the longest and most valuable temperature records in the European Alps – despite several dislocations of the measurements site, which is now located at the World Radiation Center within roughly 1 km distance from the Davos Seehornwald site.



Total snow height measured at the Davos MeteoSwiss station (calculated from daily values 1997–2017).



Average montly air temperatures for April (red) and November (blue) (calculated from daily mean values 1997–2018), and linear trends (dashed lines).

Geology and Soils

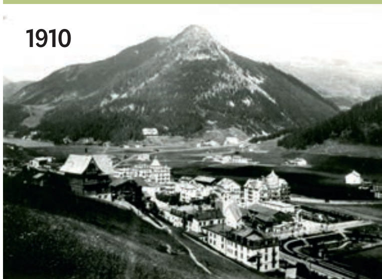
The Seehorn mountain to the east of the site is the dominant topographic feature and gives the forest the local name “Seehornwald” (forest of the Seehorn mountain). Its silicious geological bedrock belongs to the wrapped Silvretta crystalline facies. A smaller hill in the west is composed of main dolomite of the Arosa nappe, a calcareous rock that does however not easily erode as the typical calcareous rocks of the pre-Alps. Thus, Davos-Seehornwald is located at the interface between silicious and dolomitic bedrock, covered by debris from the Seehorn in combination with moraine debris from the last (Würmian) glaciation ca. 20,000 years ago.

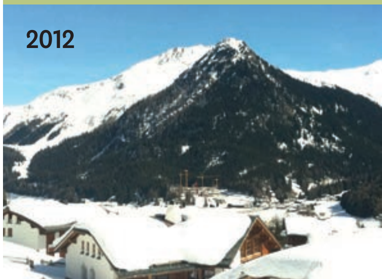
Soils are ferralic podzols with a pH value typically below 4 and rich in boulders and rocks. The mean carbon stock in the flux footprint area is 142.3 t C ha^{-1}, and the nitrogen stock was quantified at 5.1 t N ha^{-1}. Roughly 30% of the total carbon stock is found in the organic layer (10 cm and more). Carbon contents are 43% in the organic layer, 11% in the Ah horizon, and 4% in the B horizon. In the rocky subsoil below 40 cm depth, the carbon content is <1%. Nitrogen contents vary between 1.1 and 1.7% in the organic layer, and between 0.3 and 2.4% in the 0–5 cm layer (Jörg 2008).

Geological map of the Seehornwald area. Yellow circle shows research site.

Land-Use History

The Seehornwald forest has been remarkably unaffected by developments in the Davos area during the past century. The largest changes occurred in the 13th century when settlers of the German speaking “Walser” provenience settled in the naturally forested area, clearing forests in the flat parts of the valley and starting agricultural activities, namely livestock grazing and extensive crop production. This led to rather intensive usage of the remaining forests along the foothills and steeper slopes surrounding the agriculturally used Davos valley. More than 80% of the Davos forests are still privately owned. Finding a common agreement between forest owners and the government in order to not overexploit forest resources remained a challenge until 1876, when the Swiss Forest Law was enacted, marking the beginning of sustainable forest management. It was however not until 1930 when grazing livestock in forests was completely abandoned. Available maps since 1845 show remarkably little change inside the forest of the Davos-Seehornwald site, but minor impacts of local harvests namely on steeper slopes, and forest regrowth at the timberline can be identified. From 1845 to 1991 the Seehornwald forest area grew slightly from 85 to 100 ha. Land-use management, natural disturbance and climate drive the forest dynamics at the site.



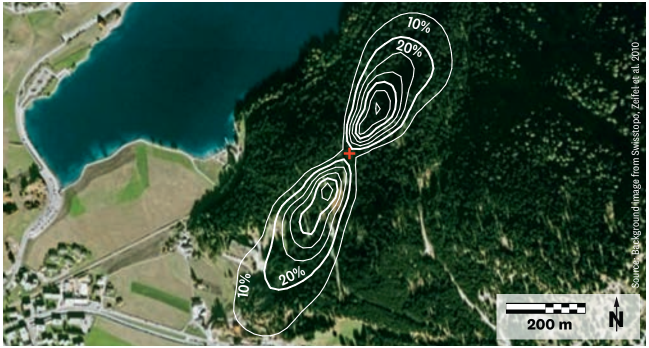


Forest development in Davos. View of Davos and Seehorn mountain with Seehornwald forest. Source: Tschopp (2012) and Dokumentationsbibliothek Davos.

Eddy Covariance Flux Measurements

The eddy covariance technique provides direct measurements of turbulent fluxes of gases like CO_2 and H_2O. In practice, two main instruments are used: (1) a three-dimensional ultrasonic anemometer-thermometer, and (2) a fast-response gas analyzer, both resolving turbulent transport with 20 measurements per second. Technically, the covariance between the two time series of vertical wind speed and gas concentration fluctuations is the vertical turbulent flux of interest. Eddies transporting and mixing CO_2, H_2O and other gases or particles in the near-surface atmosphere typically have a diameter of up to 1000 m and are observed over a period ranging from a few minutes up to an hour or so, when measurements are carried out on the top of a tower. To cover most of this timescale a typical averaging time for fluxes is 30 minutes. Hence, eddy covariance fluxes are reported with half-hourly resolution.

First attempts to measure CO_2 fluxes continuously using the eddy covariance method started in 1995, when Rudolf Häsler from WSL added instrumentation to the existing 35 m tower of the National Air Pollution Monitoring Network (NABEL). The first generation of instruments consisted of a Gill R2 anemometer-thermometer and a LI-COR 6262 closed-path in-



Satellite image, location of flux tower (red cross) and footprint area of Davos-Seehornwald, computed with the footprint model of Kljun et al. (2004). The isolines show lines of equal relative footprint weights with respect to the point of maximum contribution during the time interval 1997–2004.

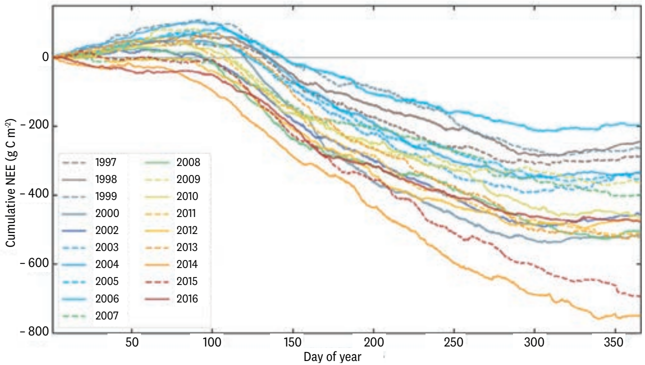
Current ICOS standard eddy covariance setup at Davos-Seehornwald, with a Gill HS-50 anemometer-thermometer and an enclosed-path LI-7200 IRGA.

frared gas analyzer (IRGA). First measurements however were not fully successful, but Dr. Häsler's team succeeded with solving the last issues in autumn 1996. Thus, continuous flux measurements started 1st January 1997, which now marks the beginning of the long-term eddy covariance flux measurement time series at Davos-Seehornwald.

Some concerns on the data quality remained as it was observed that CO_2 concentrations were always lower than expected during flux measurements, despite regular calibrations of the IRGA. Thus, Werner Eugster from ETH Zurich and Rudolf Häsler decided to carry out an in-depth on-site investigation of the issue on 28 September 2004 using an independent CIRAS IRGA, which helped to solve the issue related to underpressure in the IRGA's sample cell via a specific correction. On 9/10 August 2005 the LI-6262 was replaced by an open-path LI-7500 device, and on 20 December 2006, the Gill R2 anemometer was replaced by a newer R3 model. The next upgrade was made in July 2014 to implement the ICOS Class 1 requirements. This time, more than two years of overlap between the old and the new instruments were chosen (until November 2016) to further increase data quality for long-term trend assessments.

Carbon Budget

Davos-Seehornwald is one of the oldest ecosystem flux sites globally (continuous eddy covariance data since 1997) and currently the only subalpine Class 1 spruce forest within ICOS RI. Over the last 20 years, the forest has been a clear net carbon sink, and this sink increased over the last 20 years, despite small forest management events. The increase can be related to higher uptake rates during summer, but also to smaller losses during winter months. Even during extreme warm and dry years, such as 2003, 2011 or 2015, the forest stayed a me-

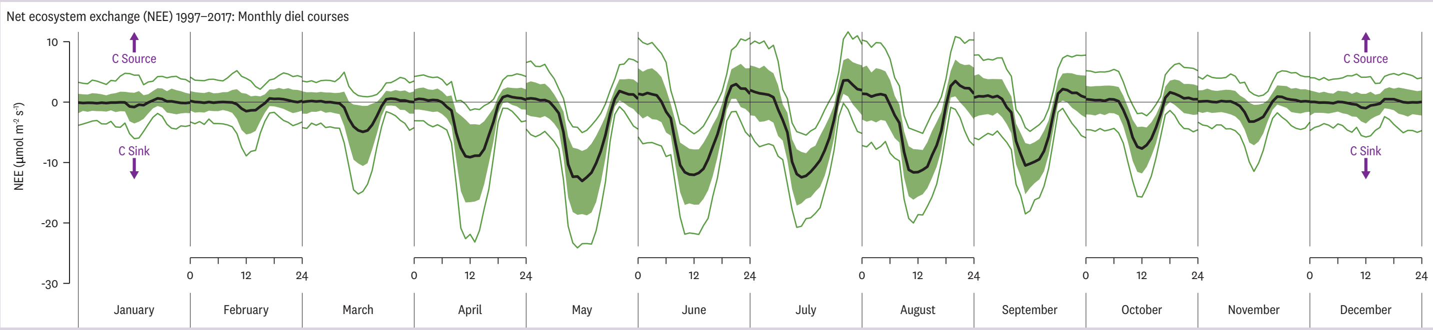


Cumulative net ecosystem exchange (NEE) measured at Davos from 1997 to 2016. Positive values indicate net CO_2 losses and negative values indicate net uptake of CO_2 (2001 is missing due to measurement problems).

Custom-made automated soil chamber.

dium to large carbon sink, also due to orographic rains. It remains to be seen how long this nutrient-poor site can sustain such long-term carbon sink behaviour. Highest uptake rates (lowest NEE) are typically measured in May, when the evergreen trees can use increasing radiation and thus temperatures for photosynthesis at high soil moisture availability, while soil respiratory losses are still low due to

relatively cold soils (Etzold et al. 2011). Under these conditions, ecosystem CO_2 losses, dominated by soil respiration, are overcompensated by high CO_2 uptake rates of the evergreen foliage and thus stem growth. Soil respiration peaks later in summer, leading to high ecosystem respiration in June and July. The relevance of spring temperatures for NEE and the overall carbon sink has increased since 1876, especially since the 1950s (Churakova et al. 2014), most likely an early sign for climate change impacts. In addition to the eddy covariance measurements, the soil—atmosphere greenhouse gas exchange is measured continuously by four automated soil chambers.

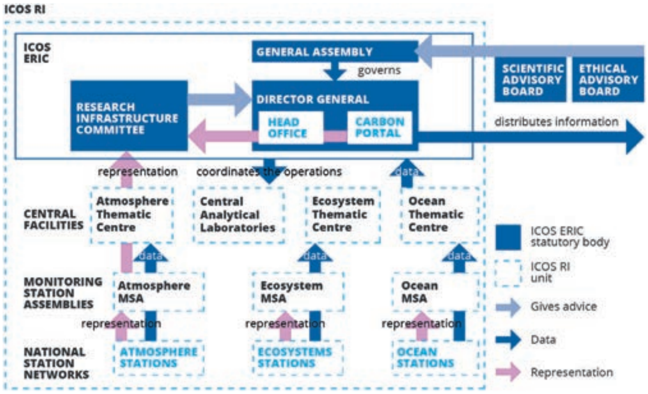


Monthly aggregated diel courses of net ecosystem exchange (1997–2017). Black line: hourly median flux; green band: median ±25% of flux measurements, thin green line: 75% confidence interval. Negative fluxes denote net CO_2 uptake, positive fluxes show net CO_2 loss.

ICOS — Integrated Carbon Observation System

The Integrated Carbon Observation System Research Infrastructure (ICOS RI) is a Europe-wide research infrastructure aiming at producing high-precision and standardized data of the carbon cycle, namely of greenhouse gases in the atmosphere and of their fluxes between atmosphere, ecosystems and oceans. In 2018, ICOS RI consisted of 12 European member and observer countries, each with their own national networks (with overall more than 140 measurement stations).

ICOS Switzerland (ICOS-CH) is a consortium of ETH Zurich, Empa, WSL, University of Bern, University of Basel, and MeteoSwiss. It is part of ICOS RI with two ICOS Class 1 stations located in the Swiss Alps, one atmospheric station (Jungfraujoch, 3580 m a.s.l.) and one ecosystem station, which is the Davos-Seehornwald site. In order to become an official ICOS station, it has gone through an extensive design and preparation phase (2006-2013, funded by EU), followed by upgrading the station according to ICOS RI requirements during the implementation phase (starting in 2013, funded by SNF and Swiss partner institutions). It was among the first stations within ICOS RI to enter the ICOS labelling process in 2016 and was officially certified as ICOS Class 1 Ecosystem station in 2019.



ICOS RI governance and structure.

Greenhouse gas measurements (continuous)

CO_2, H_2O vapour (eddy covariance & profile for storage)
CH_4 and N_2O fluxes (eddy covariance & profile for storage)
Soil CO_2, CH_4 and N_2O fluxes by automatic chambers

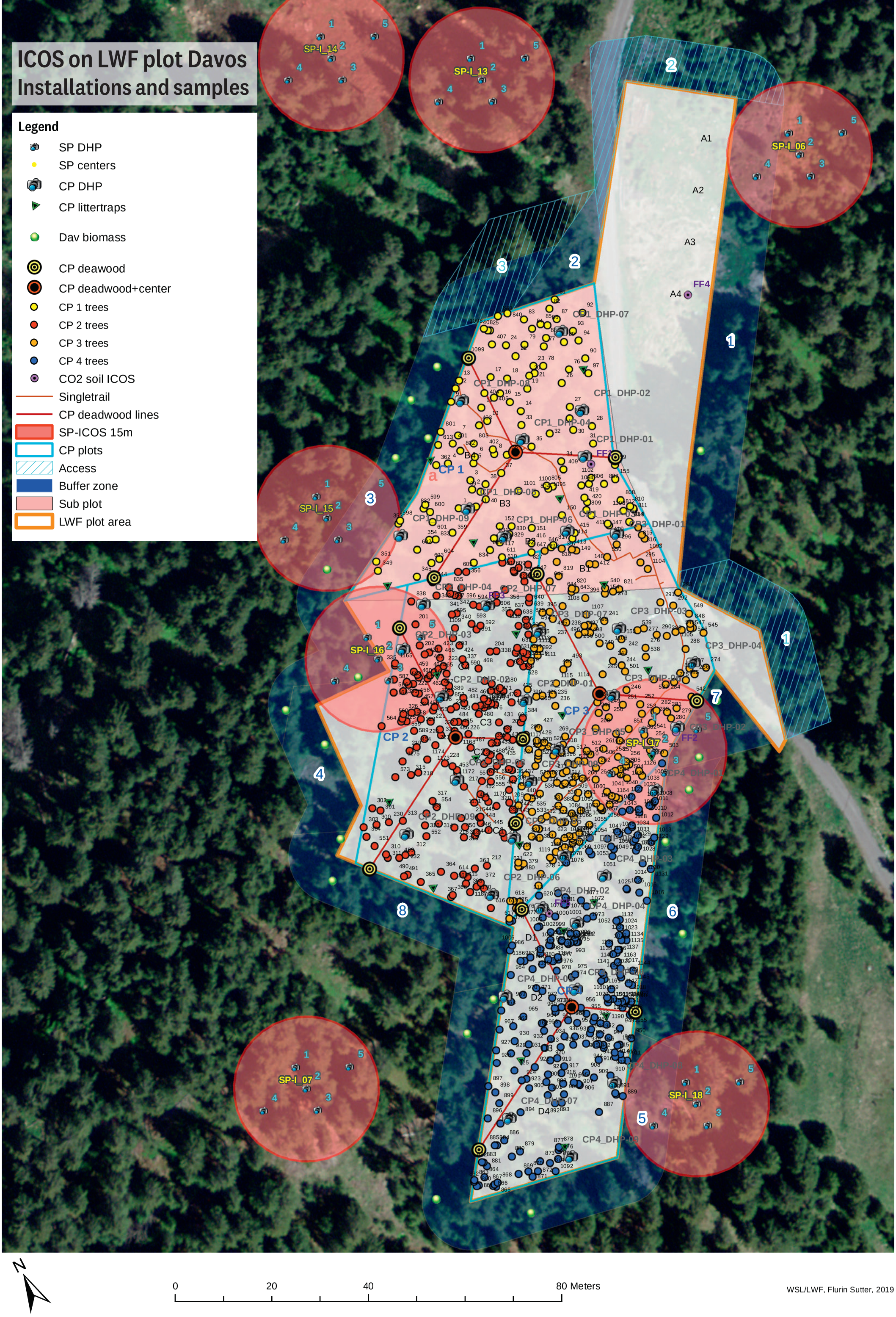
Ecosystem

Water table depth
Tree diameter (continuous)
Phenology
Green area index
Above ground biomass
Soil carbon content
Litterfall
Leaf nutrient content
C and N import/export by management
Management and disturbance information

Meteorology (continuous)

Wind speed and wind direction (additional to 3D sonic)
Incoming, outgoing and net SW and LW radiations
Incoming PPFD
Outgoing PPFD
Diffuse PPFD and/or SW radiation
Soil heat flux
Air temperature and humidity profile
Backup meteo station (TA, RH, SW_IN, precipitation)
Total precipitation (high accuracy)
Snow height
Soil water content profile
Soil temperature profile
Air pressure

List of variables required for an ICOS Class 1 forest station.

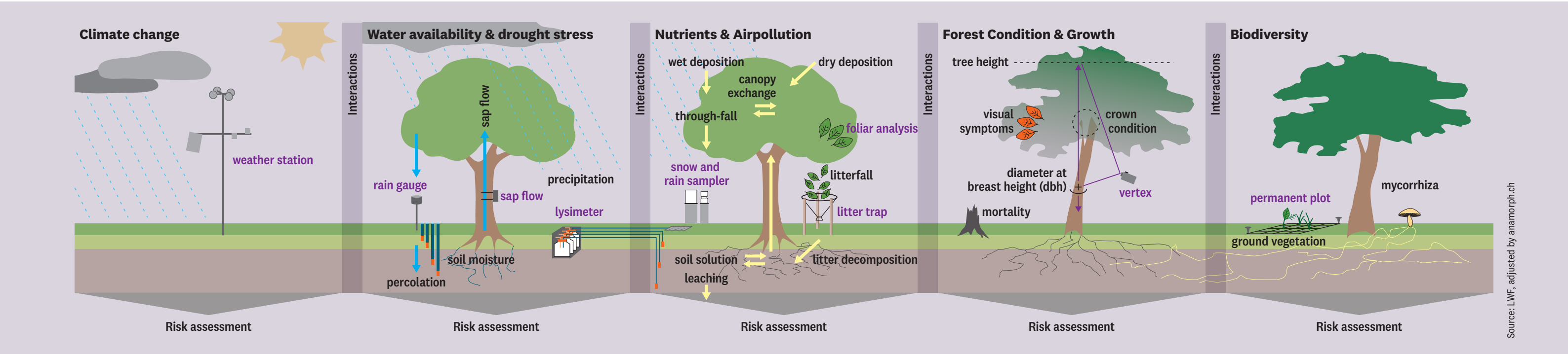


ICOS on LWF plot Davos
Installations and samples
Legend
SP DHP
SP centers
CP DHP
CP littertraps
Dav biomass
CP deawood
CP deadwood+center
CP 1 trees
CP 2 trees
CP 3 trees
CP 4 trees
CO2 soil ICOS
Singletrail
CP deadwood lines
SP-ICOS 15m
CP plots
Access
Buffer zone
Sub plot
LWF plot area
SP-I_14
SP-I_13
SP-I_06
SP-I_15
SP-I_16
SP-I_17
SP-I_07
SP-I_18
CP 1
CP 2
CP 3
A1
A2
A3
A4
FF4
FF2
N
0
20
40
80 Meters
WSL/LWF, Flurin Sutter, 2019

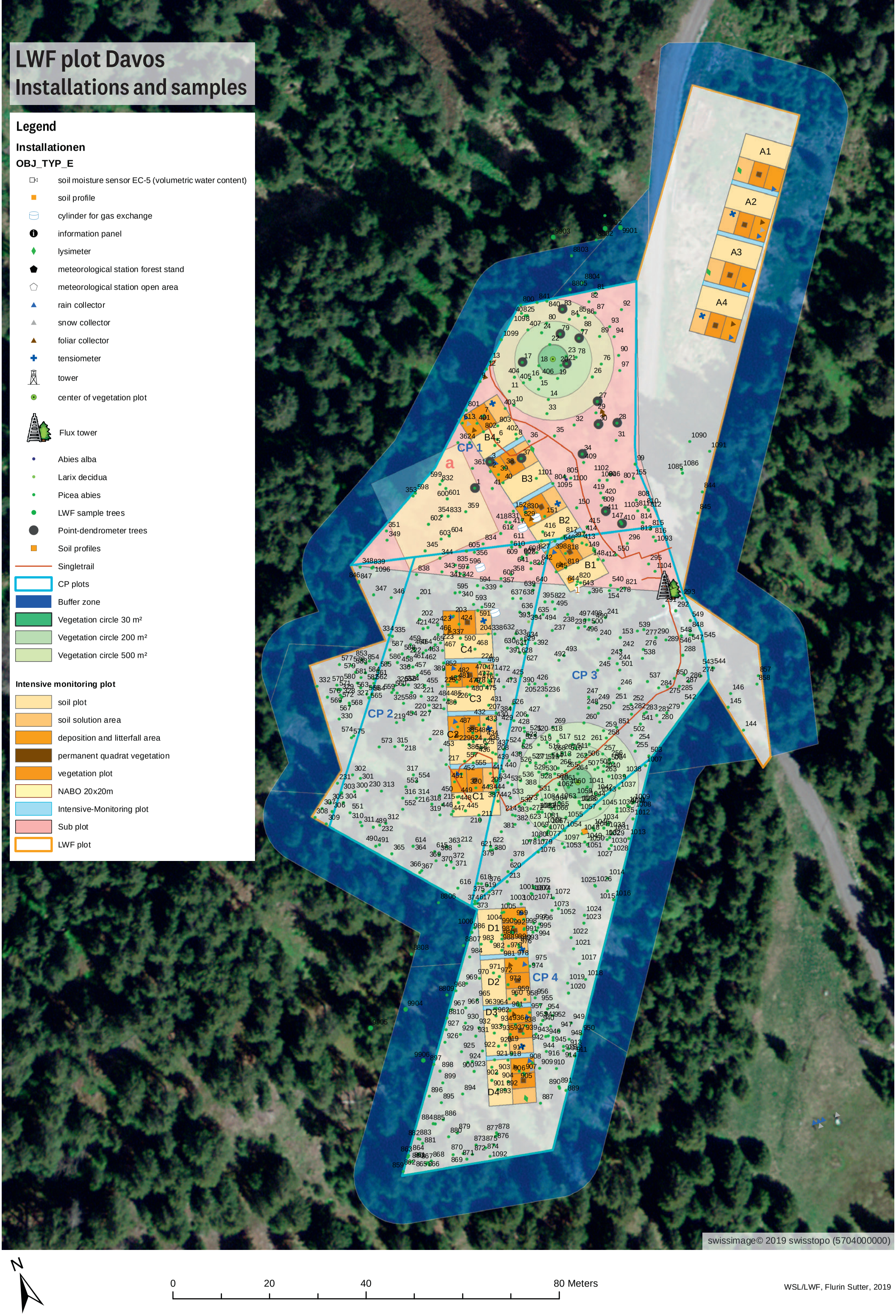
LWF — Long-term Forest Ecosystem Research

The Long-term Forest Ecosystem Research (LWF) program examines effects of air pollution and climate change on forests in

Switzerland. The aim is a representative monitoring of the forest health (Sanasilva inventory) and an increased understanding of how natural and anthropogenic stresses affect forests in the long term. LWF includes a representative 16×16 km grid (Sanasilva) and 19 permanent intensive monitoring sites (LWF plots) in Switzerland. It contributes to the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests) and is part of the LTER-Europe Network (Long-Term Ecosystem Research in Europe). Davos-Seehornwald was integrated into LWF in 2006 and is structured in a plot, a sub-plot, and 16 10×10 m^2 intensive monitoring plots (IM plots), two circular vegetation plots, and a buffer zone. Here, the following variables are measured on different time scales: Annual crown condition and forest health (sub-plot), annual leaf area index with hemispherical photos (IM plots), foliar nutrients (5 trees in buffer zone), vegetation composition (IM plots and circular plots), soil nutrients (once on whole plot in 2008), continuous soil water content (IM plot), litterfall (IM plot) and nitrogen deposition (IM plot).



Overview of the types of measurements performed and sensors installed by LWF at Davos-Seehornwald.


LWF plot Davos
Installations and samples
Legend
Installationen
OBJ_TYP_E
soil moisture sensor EC-5 (volumetric water content)
soil profile
cylinder for gas exchange
information panel
lysimeter
meteorological station forest stand
meteorological station open area
rain collector
snow collector
foliar collector
tensiometer
tower
center of vegetation plot
Flux tower
Abies alba
Larix decidua
Picea abies
LWF sample trees
Point-dendrometer trees
Soil profiles
Singletrail
CP plots
Buffer zone
Vegetation circle 30 m²
Vegetation circle 200 m²
Vegetation circle 500 m²
Intensive monitoring plot
soil plot
soil solution area
deposition and litterfall area
permanent quadrat vegetation
vegetation plot
NABO 20x20m
Intensive-Monitoring plot
Sub plot
LWF plot
A1
A2
A3
A4
B1
B2
B3
B4
C1
C2
C3
C4
D1
D2
D3
D4
CP 1
CP 2
CP 3
CP 4
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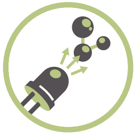
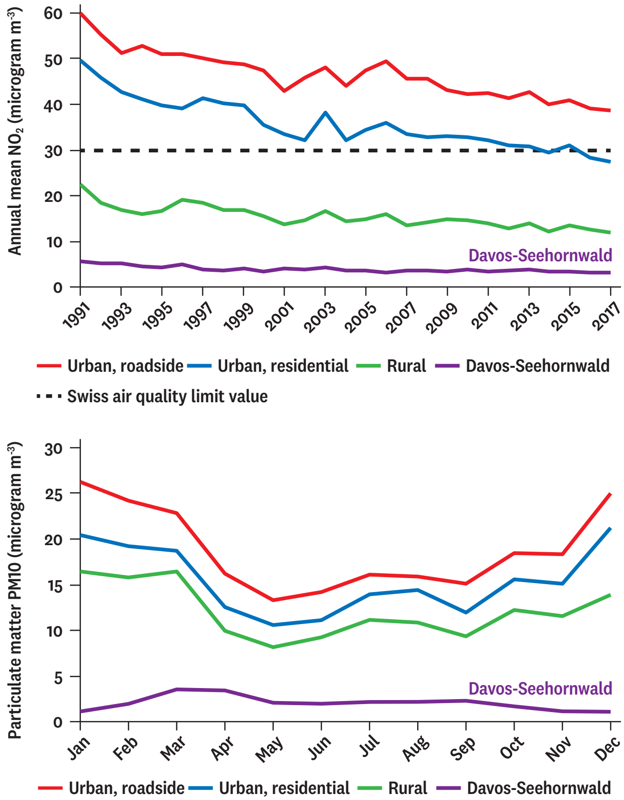
80 Meters
WSL/LWF, Flurin Sutter, 2019

NABEL — National Air Pollution Monitoring Network

The National Air Pollution Monitoring Network (NABEL) is a joint activity of the Swiss Federal Office for the Environment (FOEN) and Empa. It measures the long-term development of air quality at 16 locations in Switzerland and is a key element of the Swiss clean air policy. The 16 stations reveal air pollution levels at representative locations (e.g. urban roadside, urban residential area, rural area). At each station, important air pollutants (e.g. nitrogen dioxide, particulate matter, ozone) as well as meteorological variables (air temperature and humidity, precipitation, radiation) are measured. Since 1985, the air quality in Switzerland has significantly improved. However, air pollution levels in Switzerland still negatively impact human health, and the existing limit values of the above mentioned air pollutants are occasionally exceeded.



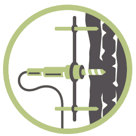
Davos-Seehornwald was established as a rural site above 1000 m a.s.l. within NABEL in 1988. As expected, the air is very clean in comparison to urban and residential areas. For ecosystem protection, it is important to quantify the atmospheric nitrogen deposition which was estimated at 10.7 kg N ha^{-1} yr^{-1} in 2016.

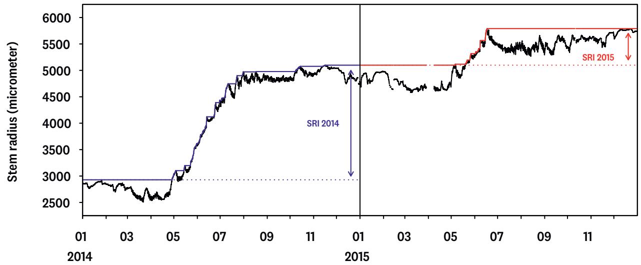


NO_2 measurements since 1991 (top) and mean annual course of PM10 (particulate matter with a diameter up to 10 micrometers, 2015–2017, bottom) in comparison with urban roadsite, urban residential and rural sites.

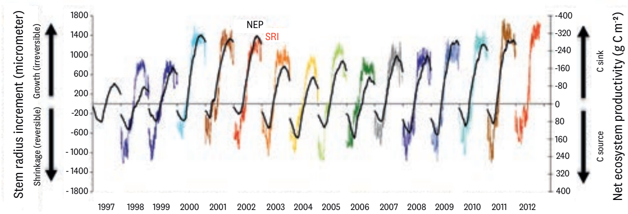
TreeNet — The Biological Drought and Growth Indicator Network

TreeNet collects continuous data on stem radius fluctuations measured with high-precision point dendrometers from about 250 trees at over 30 sites in Switzerland and estimates drought and growth indicators for Swiss forest ecosystems. The data include irreversible seasonal stem growth processes on the one hand and reversible diurnal shrinkage and expansion of the bark related to the transpiration of the tree on the other hand. Key questions within TreeNet are: When do trees grow? Are there site- and species-specific growth differences? What is actually driving tree growth and what are growth limiting factors? When is stem shrinkage most distinct and what does it tell us about drought stress of trees? Further, TreeNet aims to link research results from eddy covariance flux sites with dendrometer data to entire landscapes. At Davos-Seehornwald, first continuous dendrometer measurements started in 1998. A remarkably close, positive relationship between net ecosystem productivity (NEP) and changes in stem radii on annual and monthly time scales was found, whereas on a half-hourly time scale the relationship was negative and reflected the diel cycle of leaf transpiration (Zweifel et al. 2010).





Stem radius changes (black) measured with a point dendrometer over two years. Stem growth (blue: 2014, red: 2015) sums up to annual stem radius increments (SRI). The difference between the black and coloured lines indicate stem shrinkage, the so-called tree water deficit.

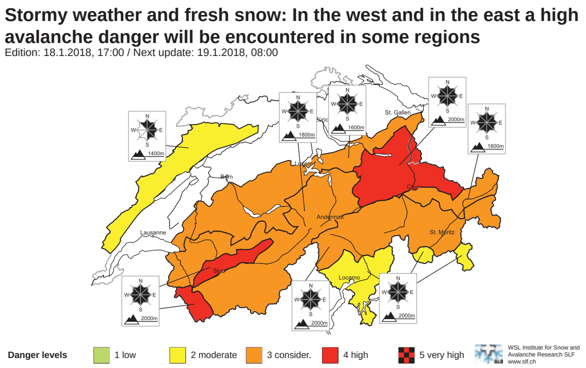


Eddy covariance-based net ecosystem productivity (NEP, positive values indicate carbon sink) in comparison with stem radius increments (SRI, positive values indicate stem growth) at Davos-Seehornwald. NEP and SRI are shown as annual cumulative values from 1997 to 2012.

Davos — A Scientific Hotspot

Davos has a long-lasting record in cutting edge research and its research institutions are well linked to Swiss Universities and the ETH domain. The Physical-Meteorological Observatory Davos (PMOD) was established in 1907. The aim was to investigate the climatically relevant properties of the health resort. The only daughter of the founder suffered from tuberculosis and sought relief in Davos. Research strongly focused on solar radiation as a means to alleviate tuberculosis infections. This led to the foundation of the World Radiation Center (WRC) in 1971. While tuberculosis research was a hot topic for several decades, the AO Research Institute Davos (ARI) focuses on osteosynthesis, the reduction and internal fixation of bone fractures with implantable devices (AO stands for “Arbeitsgemeinschaft für Osteosynthesefragen”). The Swiss Avalanche Research Institute (SLF, part of WSL) has been a world leader in snow and avalanche research since 1936. All aspects from snow crystal processes to the devastating forces of avalanches are investigated. In 1996, the headquarters were moved to the research building at the Flüela road. In winter, the SLF issues daily avalanche forecasts that are carefully checked by skiers and those working outdoors.

Radiation measurements on the roof of the World Radiation Center (WRC).



Example of a SLF avalanche bulletin showing avalanche danger levels on 18 January 2018.

Research Site History

1985 First measurements by WSL as part of the Swiss National Science Foundation project NRP14/14+ about air pollution and forest health investigations.

1986–1988 Installation of a 35 m tall tower and a 25 m scaffold around two trees. Start of continuous monitoring campaigns including air chemistry and deposition variables, microclimate profiles through the canopy, soil property measurements, litter fall and gas exchange measurements of individual branches. During this time, a 0.25 ha plot of the forest is mapped, the properties of each tree are measured, and the site is established as a NABEL (National Air Pollution Monitoring Network) site.

1991 Start of continuous atmospheric NO, NO_2, and O_3 measurements by NABEL.

1995 First attempts to measure the CO_2 exchange with the eddy covariance method.

1996 Installation of vertical CO_2 and microclimate profiles.

1997 The eddy covariance equipment reaches its full functionality and continuous eddy covariance flux measurements are started on 1st of January.

1998 Continuous measurements of stem radius fluctuations by automatic point dendrometers start.

2006 The site becomes part of the Swiss Long-term forest ecosystem research programme (LWF) and with that of the International Co-operative Programme on Assessment and Monitoring of Air Pollution Effects on Forests (ICP Forests). The Grassland Sciences Group of ETH Zurich takes over responsibilities for the eddy covariance and microclimatic measurements and the site becomes a core site of the Swiss FluxNet.

2006 Harvesting within the northeastern part of the eddy covariance footprint (1750 m^2).

2008 The site becomes part of the Integrated Carbon Observation Research Infrastructure (ICOS-RI).

2009 Start of continuous measurements of CO_2 concentrations in tree stems.

2011 The site becomes part of the biological drought and growth indicator network (TreeNet).

2013 Extension of NABEL measurements to include atmospheric particulate matter with a diameter up to 10 micrometers (PM10). Start of upgrading the site to ICOS Class 1 level.

2014 The site gets an additional 5 m buffer zone around the core monitoring area, resulting in a new overall research area of 11,000 m^2. Flux measurements of CH_4 and N_2O above the canopy (eddy covariance) and from the soil (automatic chambers) are started within the ICOS framework.

2018 Extension of NABEL measurement to include atmospheric particulate matter with a diameter smaller than 2.5 micrometers (PM2.5).

2019 The site gets officially certified as ICOS Class 1 Ecosystem station.

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