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Non-CO2 Forcers and their Climate, Weather, Air Quality and Health Impacts

FOCI

Deliverable 2.1

In-situ long-term datasets of aerosol, BVOC, CO2 fluxes and meteorological data

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EXECUTIVE SUMMARY

This document is the deliverable “D 2.1 In-situ long-term datasets of aerosol, BVOC, CO2 fluxes and meteorological data” for the European Union project “FOCI: Non-CO2 Forcers and their Climate, Weather, Air Quality and Health Impacts” (hereinafter also referred to as FOCI, project reference: 101056783).

The observations described in this Deliverable contribute to the FOCI integrated observational and modelling analysis with a particular focus on natural and biogenically dominated environments. The deliverable provides a scientific summary of the feedback analysis and provides an access point for a data set that will be evolving during the FOCI project (living data set).

CONTRIBUTION TO THE FOCI OBJECTIVES

The Deliverable 2.1 initiates the analysis and data development in WP 2 towards climate feedbacks in the biogenically dominated environments. In practice, the D 2.1 contributes to the following FOCI objectives:

1. To examine and evaluate the climate relevant processes and feedbacks of natural aerosols and BVOCs, as precursors for SOA based on new and available observations datasets (WP2). These are to be contrasted with the feedbacks of anthropogenic primary and secondary aerosols compiled in WP 1.
2. To integrate observational and modelling datasets and data products for improving and evaluating multiscale climate and atmospheric composition models (cross-cutting activity). The data set is available for the consortium for further analysis in WP2 by developing a growth rate analysis tool as well as for contrasting dataset for models in the biogenically dominated environments.

1. INTRODUCTION

The deliverable provides a scientific summary of the feedback analysis and provides an access point for a data set that will be evolving during the FOCI project (living data set).

Feedbacks can be either positive or negative, indicating that they tend to either speed up or slow down the change, respectively. Driven by elevated concentrations of CO2 in the atmosphere, COntinental Biosphere-Aerosol-Cloud-Climate (COBACC) feedback (Kulmala et al., 2004, Figure 1) connects atmospheric temperature increase to elevated terrestrial ecosystem photosynthesis (gross primary production, GPP) and consequently higher biogenic volatile organic compound emissions and secondary organic aerosol formation and growth leading to increase in Cloud Condensation Nuclei (CCN) concentrations and in Cloud Droplet Number Concentrations (CDNC). With the same amount of liquid vapor, this leads to smaller cloud droplet effective radii and consequently higher cloud albedo. This feedback tends to hinder global warming, confirmed in Paasonen et al. (2013) and with full observational evidence in Petäjä et al. (2022).

The bottom half of the COBACC-feedback was quantified by Kulmala et al. 2004 and refined by Kulmala et al. (2014). The driving processes of the feedback are the same as described above, but the connection back to enhanced gross primary production is channelled through elevated aerosol surface area leading to changes in the ratio between the diffuse and direct solar radiation. The increased scattering aerosol layer leads to increased fraction of solar radiation to reach the terrestrial ecosystem as diffuse radiation, which is more distributes the radiation more effectively below the canopy and enhances the photosynthesis of the whole biosphere. Consequently, the photosynthesis and gross primary production increases leading to higher carbon dioxide uptake that tend to cool the climate. Both of these feedbacks in Figure 1 are modulating the radiation balance in the biogenic dominated environments towards slowing down the climate change.

In a large fraction of global environments, the aerosol population is significantly influenced by anthropogenic direct (primary) particle emissions. In these environments, the feedback mechanism is modulated (Figure 1) as these emissions provide an independent source of CCN (Pasonen et al., 2013) as well as they alter aerosol surface area and therefore the ratio between the diffuse and direct solar radiation. Therefore, for a more realistic analysis, it is beneficial to include a sub-set of comprehensive data sets that are occasionally and intermittently influenced by anthropogenic emissions (Figure 1).

We expand, by including more observation sites and longer data sets, the feedback analysis performed in Paasonen et al. (2013) that connects the aerosol formation, growth, CCN concentrations and changes in cloud albedo. We further explore the feedback between the aerosol formation and growth that influence radiative transfer through the atmosphere increasing the contribution of diffuse radiation. This increases the gross primary production of the biosphere, thus leading to a negative feedback mechanism hindering warming in the biogenically dominated environments (Kulmala et al. 2004; Kulmala et al. 2014; Kulmala et al. 2020; Kulmala et al. 2023). Finally, we aim to investigate the influence of changes in cloud albedo to gross primary production, which may weaken the impacts of the above negative feedback effects.

The collected data set will be utilized in the harmonized analyses of aerosol growth rates later in the FOCI-project. This will provide additional insights into the aerosol growth to CCN sizes in different environments and make it possible to quantify the influence of contributing factors, e.g., anthropogenic pollution, to the processes. Further insights are explored utilizing time-over-land concepts (Tunved et al. 2006; Petäjä et al. 2022; Räty et al. 2023) and air mass exposure to anthropogenic emissions (Hakala et al. 2021).

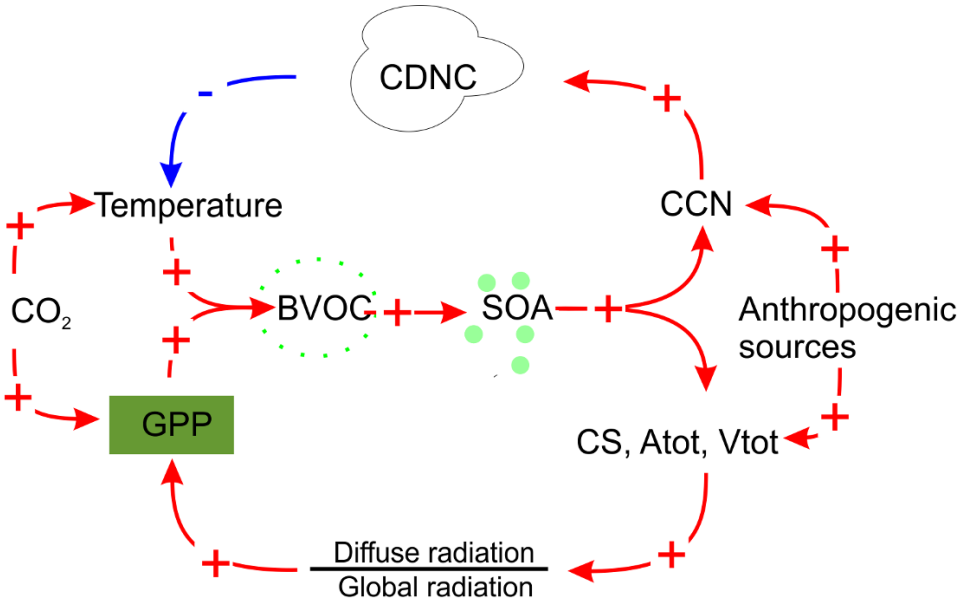

Figure 1: *Biophysical feedbacks between the biosphere and the atmosphere (modified from Kulmala et al. 2014). Both feedbacks are driven by an increase in atmospheric CO2 concentrations. In the real atmosphere, the biogenic feedbacks are modulated by anthropogenic emissions.* ***Top feedback:*** *increase in temperature --> increase in BVOC concentrations --> increase in growth rate and/or survival probability of tropospheric aerosol particles to sizes where they can act as CCN --> changes in cloudiness, cloud droplet number concentrations and cloud effective radius --> decrease in temperature;* ***Bottom feedback:*** *increase in gross primary production ---> increase in BVOC concentrations --> increase in growth of tropospheric aerosol particles --> increase in aerosol surface area and CS --> increase in diffuse radiation --> increase in productivity --> increase in GPP. Acronyms: BVOC = biogenic organic volatile compounds; GPP = gross primary production (photosynthesis); SOA = secondary organic aerosols; CCN=cloud condensation nuclei; CDNC = cloud droplet number concentration; CS, Atot, Vtot=parameters describing aerosol concentration affecting light scattering.*

2. SHORT DESCRIPTION OF THE SITES OF OUR INTEREST

This section provides a concise description of the identified and contacted observation sites that can provide relevant data for the feedback analysis. A map of the identified sites is presented in Figure 2, which shows the potential towards a global data set. The observation sites with available processed datasets are listed in Table 1. As new observations become available, the list of observation sites will be updated as well.

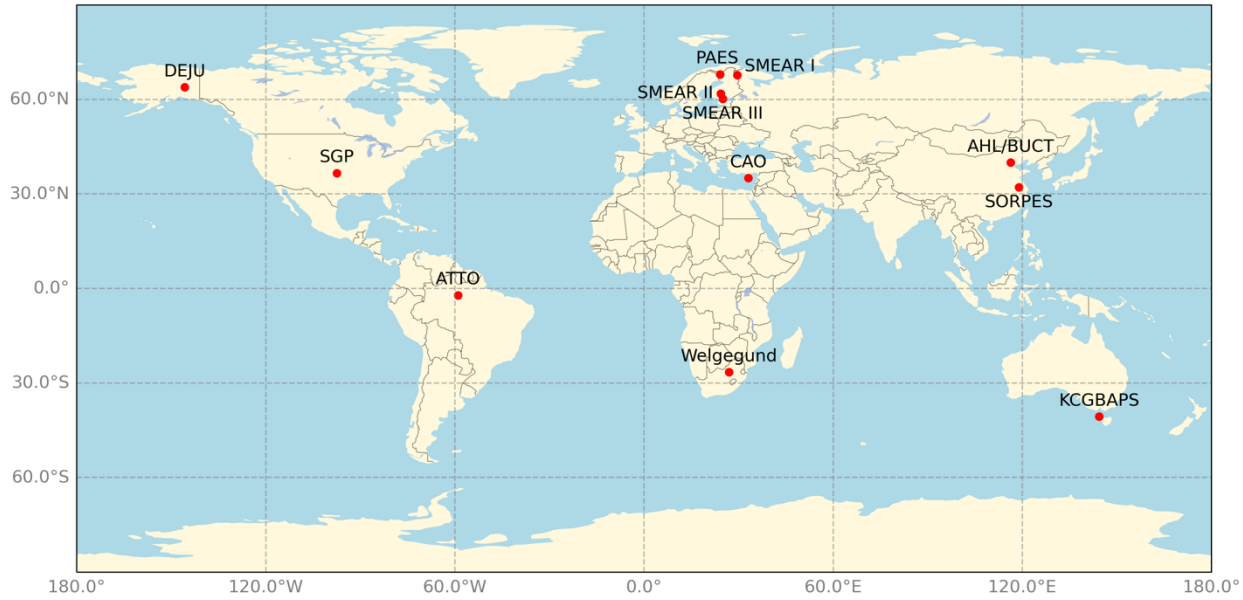

Figure 2: *Identified comprehensive observation sites that have the capacity to provide data for the biogenic and anthropogenic feedback analysis. The observation sites are marked with red markers and annotated with station short names. The acronyms are listed here. SMEAR: Station for Measuring Ecosystem-Atmosphere Relations; PAES: Pallas Atmosphere-Ecosystem Supersite; CAO: Cyprus Atmospheric Observatory; SGP: Southern Great Plains; DEJU: Delta Junction; ATTO: Amazon Tall Tower Observatory; SORPES: Station for Observing Regional Processes of the Earth System; AHL/BUCT: Aerosol and Haze Laboratory/Beijing University of Chemical Technology; KCGBAPS: Kennaook/Cape Grim Baseline Air Pollution Station.*

Table 1: *List of available processed datasets (marked by X) collected from various measurement sites, as well as their names, units, time resolutions, aggregate methods after processing. The acronyms are listed here. T: air temperature; RH: relative humidity; prec: accumulated precipitation; pres: air pressure; rad_glob: incoming direct solar radiation; rad_diff: incoming diffuse solar radiation; CO2_flux: CO2 flux; GPP: gross primary production; NEE: net ecosystem exchange; SO2: mixing ratio of sulfur dioxide: O3: mixing ratio of ozone; NO: mixing ratio of nitric oxide; NO2: mixing ratio of nitrogen dioxide; VOC: mixing ratio of volatile organic compound; PN: particle number concentration; PNSD: particle number size distribution; CCN: number concentration of cloud condensation nuclei.*

Name	Unit	Interval	Aggregate	SMEAR I	SMEAR II	SMEAR III	CAO
T	degC	Hourly	Mean, Median	X	X	X	X
RH	%	Hourly	Mean, Median	X	X	X	X
prec	mm	Hourly	Sum	X	X	X	X
pres	hPa	Hourly	Mean, Median	X	X	X	X
rad_glob	W m-2	Hourly	Mean, Median	X	X	X	X
rad_diff	W m-2	Hourly	Mean, Median		X		X
CO2_flux	umol m-2 s-1	30 min	Original	X	X	X	
GPP	umol m-2 s-1	30 min	Original	X	X[1]		
NEE	umol m-2 s-1	30 min	Original	X	X		
SO2	ppbv	Hourly	Mean, Median	X	X	X	X
O3	ppbv	Hourly	Mean, Median	X	X	X	X
NO	ppbv	Hourly	Mean, Median	X	X	X	X
NO2	ppbv	Hourly	Mean, Median	X	X	X	X

VOC	ppbv	Hourly	Mean, Median		X[2]		X[3]
PN	cm-3	Hourly	Mean, Median	X	X	X	X
PNSD	cm-3	Hourly	Mean, Median	X	X	X	X
CCN	cm-3	Hourly	Mean, Median		X[4]		

1: Only including hourly mean data
2: M137 (monoterpenes), M69 (isoprene + MBO)
3: acetylene, a-pinene, benzene, b-pinene, ethane, ethyl-benzene, ethylene, i-butane, i-pentane, mp-xylenes, n-butane, n-pentane, o-xylene, propane, propene, toluene
4: CCN at supersaturation of 0.1%, 0.2%, 0.3%, 0.5% and 1.0%.

The primary data set that we aim to collect includes the parameters crucial for the quantification of the feedbacks presented in Figure 1. We list the variables and their relevance in Table 2 below. Additional categories will be included, when needed. We do not limit the site-specific data sets to be from a same specific year. However, at minimum, we expect at least one year of observational data to explore the seasonal cycle of parameters. However, longer datasets are favoured as they provide an opportunity to explore interannual variability.

Table 2: *Relevant parameters for the feedback analysis.*

Category	**Critical parameters**	**Supporting data**
Meteorology	Temperature, diffuse radiation, global radiation	Relative humidity, precipitation, pressure, other radiation parameters, cloudiness
Ecosystem data	CO2 flux, NEE, GPP	Sensible heat flux, latent heat flux, other flux data
Trace gas data	VOC	CO2, SO2, O3, NOx, CO
Aerosol data	Aerosol size distribution	Cloud condensation nuclei concentration, total aerosol number concentration, aerosol chemical composition

2.1 Northern Europe/Baltic

Hyytiälä, Finland. The Station for Measuring Ecosystem-Atmosphere Relations II (SMEAR II) at Hyytiälä is in southern Finland 60 km northeast from Tampere (61°51' N, 24°17' E, 181 m a.s.l.; Hari and Kulmala, 2005). The station is equipped with extensive facilities to measure forest ecosystem–atmosphere interactions continuously and comprehensively. A rather homogeneous coniferous boreal forest surrounds this rural continental station. The SMEAR II in Hyytiälä contributes to ACTRIS aerosol and trace gas in-situ component, ACTRIS cloud remote sensing, ICOS atmospheric observations and eLTER ecosystem observations. The long-term perspective of the data is presented in Neefjes et al. (2022).

Värriö, Finland. The Station for Measuring Ecosystem-Atmosphere Relations I (SMEAR I) site in Värriö is on top of the Kotovaara fjell, surrounded by a 65-year-old Scots pine forest (67°45' N, 29°36' E, 390 m a.s.l.). The station is close to the Finnish–Russian border and is occasionally influenced by the anthropogenic emissions from the Kola Peninsula industrial areas 200–300 km northeast and east from the station (Kyrö et al., 2014). The Värriö site contributes to ACTRIS aerosol in-situ

observations. It is ICOS ecosystem site and contributes to eLTER ecosystem observations.

Helsinki, Finland. The Station for Measuring Ecosystem-Atmosphere Relations III (SMEAR III) site in Helsinki is in the University of Helsinki campus area (60°12' N, 24°58' E, 26ma.s.l.; Hussein et al., 2008; Järvi et al. 2009). The site is located next to a busy road on a hill elevated by 20 m from the surrounding area.

Pallas, Finland. The Pallas Global Atmospheric Watch (GAW) site (also known as Pallas Atmosphere-Ecosystem Supersite) (67°58' N, 24°07' E; 565 m a.s.l.) is in northern Finland. The main station building is within a natural park area, on top of a hill above the tree line (Hatakka et al., 2003; Lohila et al., 2015). It is surrounded by vegetation of low vascular plants, moss, and lichen. The environment is representative of remote sub-Arctic and boreal forests. The station contributes to numerous European and global research programs, such as GAW, ICOS, ACTRIS, and EMEP.

2.2 Other European continent

Agia Marina Xyliatou, Cyprus. The Cyprus Atmospheric Observatory (CAO) AMX-site is a background station located close to the villages of Agia Marina and Xyliatos in Cyprus (35.04N, 33.06 E, 535 m a.s.l.). The atmospheric observations from the site go back to 1997 with air quality observations (Kleanthous et al. 2014). Those have been complemented with state-of-the-art aerosol and trace gas measurements since 2015 (Baalbaki et al. 2021). Currently CAO-AMX hosts various international networks including ACTRIS, Aeronet, GAW and EMEP.

2.3 North America

Southern Great Plains, US. The Southern Great Plains (SGP) site is in Grant County at north Oklahoma in the US, representing a mid-latitude, mid-continental rural environment composed of mixed farming and grassland (Parworth et al., 2015). Its Central Facility locates at 36.61° N, 97.49° W, 316 m a.s.l.. The site was established in 1992 and is the first measurement site of Atmospheric Radiation Measurement (ARM) program. It provides long-term in situ and remote-sensing multivariable observations, including variables related to meteorology, radiation, cloud, aerosol, etc (Sisterson et al., 2016).

Delta Junction, US. The Delta Junction (DEJU) subarctic measurement site (63.88° N, 145.75° W, 529 m a.s.l.), operated by National Ecological Observatory Network (NEON) and Atmospheric Science and Chemistry mEasurement NeTwork (ASCENT), is in central Alaska, US, 15 km south of Delta Junction city, 30 km south of the confluence of the Tanana and Delta Rivers. It is surrounded by various vegetation types depending on elevation and drainage, e.g., aspen (*Populus tremuloides*), Alaska paper birch (*Betula neoalaskana*), and white spruce (*Picea glauca*) on the upland sites, black spruce (*Picea mariana*) on the impeded drainage sites, and mosses, sedges, and shrubs on the poorest drainage sites. The online instrumentation systems started to produce data in 2017 (Krauss et al., 2018; https://www.neonscience.org/field-sites/deju; https://ameriflux.lbl.gov/sites/siteinfo/US-xDJ).

2.4 South America

Amazon Tall Tower Observatory, Brazil. The Amazon Tall Tower Observatory (ATTO) site is 150 km northeast of Manaus in Brazil in the central Amazon Basin (the coordinate of ATTO Tall Tower is 02°08.752' S, 59°00.335' W), representing a tropical rainforest environment with a rainy season from February to May and a drier season from June to October. The site is located at 120 m a.s.l. on a plateau and is about 12 km northeast of the Uatumã River. It is surrounded mainly by non-flooded forests (terra firme) and seasonally flooded black-water forests (igapó). The continuous measurements of multitude parameters, including carbon dioxide, ozone, volatile organic compounds, trace gases, aerosols, meteorology, etc., have been conducted since 2011. The observation at ATTO is featured by three towers, an 81 m triangular mast, an 80 m walk-up tower and a 325 m ATTO Tall Tower, enabling the measurements of vertical profiles and fluxes from ground to the tower top. More details refer to Andreae et al. (2015).

2.5 Asia

SORPES, China. The Station for Observing Regional Processes of the Earth System (SORPES) was established in 2011 and developed by Nanjing University in collaboration with the University of Helsinki. The central measurement site locates on a top of a hill about 40 m a.g.l (54 m a.s.l.) in the Xianlin Campus of Nanjing University in the suburban area about 20 km away from the Nanjing downtown area (32°07'14" N, 118°57'10" E). The site is generally upwind of Nanjing while remotely downwind of the developed mid-Yangtze River Delta (YRD) regions including densely populated large cities, e.g., Shanghai. Therefore, it can be considered as a regional background station in the YRD region of eastern China. The continuous measurements of trace gases, aerosols, and meteorological parameters have been conducted since 2011 (Ding, et al., 2013; Qi, et al., 2015).

AHL/BUCT, China. The Aerosol and Haze Laboratory/Beijing University of Chemical Technology Station (AHL/BUCT Station), built in the downtown area in Beijing, is about 9 km east from Xishan Mountain and about 30 km south from Jundushan Mountain. The measurement station is on the rooftop of the main teaching building at about 18 m a.g.l (75 m a.s.l.) in the west campus of Beijing University of Chemical Technology (39°56'31" N, 116°17'52" E). It is surrounded by three traffic roads and thus represents a typical urban environment affected by traffic and residential emissions. The trace gases, particle number size distribution, particle mass, particle composition and meteorological parameters have been measured continuously since 2018 (Liu et al., 2020).

2.6 South-Africa

Welgegund, Republic of South Africa. The Welgegund measurement station is in a privately owned farm within the Dry Highveld Grassland bioregion at the height of 1480 m a.s.l., about 25 km northwest of Potchefstroom and about 100 km southwest of Johannesburg (26°34'10" S, 26°56'21" E). The site is surrounded by grazed grassland savannah with wet season from October to April and dry seacon from mid-May to mid-September. It can be considered as a background site with few local anthropogenic sources, while at the same time can also be affected by the polluted air mass transported from Johannesburg. The site is currently operated jointly by the North-West University (NWU), the Finnish Meteorological Institute (FMI) and the University of Helsinki (UH), providing continuous

measurements of trace gases, particle number size distribution, aerosol optical properties, meteorological parameters, etc., since 2010 (Vakkari et al., 2014; https://en.ilmatieteenlaitos.fi/welgegund-reseach-station).

2.7 Australia

Kennaook/Cape Grim Baseline Air Pollution Station, Australia. The Kennaook/Cape Grim Baseline Air Pollution Station (KCGBAPS) is situated on a coastal cliff with 94 m a.s.l. at the northwest of Tasmania, Australia (40°41' S, 144°41' E). The site can measure true background air, especially when the air is sampled from the "baseline" sector (wind direction ranges from 190 to 280) from which the air could be transported several thousand kilometres over the Southern Ocean since the last land contact. The first atmospheric composition measurement in this site was conducted in 1976 and continued since then. Currently, it provides long-term measurements of greenhouse gases (GHGs), ozone depleting substances, aerosols including black carbon, reactive gases, solar radiation, etc (Gras and Keywood, 2017; https://research.csiro.au/acc/capabilities/cape-grim-baseline-air-pollution-station/).

3. DATA COLLECTION AND HARMONIZATION

3.1 Data collection

Hyytiälä, Finland. The measurement data at this station were downloaded from the publicly available data portal https://smear.avaa.csc.fi/download. The hourly mean and median data were downloaded for the variables with measurement time resolution of 1 minute to 10 minutes. One exception is the precipitation, which was downloaded as hourly summed data, because it is measured as the accumulated liquid water equivalent during previous 1 minute. The carbon dioxide flux (CO2_flux) and net ecosystem exchange (NEE) were calculated every half hour and saved in the data server, so their data were downloaded directly without making hourly mean or median. The hourly mean of another dataset of NEE (NEE2) and the gross primary production (GPP2) data were obtained from Tuomo Nieminen (tuomo.nieminen@helsinki.fi), originally from a winter course and Neefjes et al. (2022). The hourly mean of cloud condensation nuclei concentration at super saturation 0.1%, 0.2%, 0.3%, 0.5%, 1.0% were obtained from Lauri Ahonen (lauri.r.ahonen@helsinki.fi).

Värriö, Finland. Similar with SMEAR II, the measurement data at this station were also downloaded from the data portal https://smear.avaa.csc.fi/download. The precipitation was also downloaded as the hourly summed data. The carbon dioxide fluxes (CO2_flux_27, CO2_flux_166 measured at 2.7 m and 16.6 m, respectively), net ecosystem exchange (NEE) and gross primary production (GPP) were measured or calculated every half hour, so their original half hourly data were downloaded. All the other variables were downloaded as both hourly mean and median.

Helsinki, Finland. Similar with SMEAR II. The precipitation data was downloaded as hourly sum. The original half-hourly carbon dioxide fluxes (CO2_flux_old, CO2_flux_new, the old and new primary measurements, respectively) data are downloaded. All the other variables were downloaded as both hourly mean and median.

Agia Marina Xyliatou, Cyprus. All the measurement data were obtained from the contact person Michael Pikridas (m.pikridas@cyi.ac.cy). Similar with SMEAR stations shown above, the meteorological data are houry mean except precipitation, which is the accumulated rainfall during previous hour. The mixing ratios of inorganic compounds (NO, NO2, NOx, SO2, O3, CO) and particle number size distribution (PNSD) are also hourly mean values. The VOC data (including ethane, ethylene, propane, propene, i-butane, n-butane, acetylene, i-pentane, n-pentane, benzene, toluene, ethylbenzene, mp-xylenes, o-xylene, a-pinene, b-pinene) are half-hourly data without outliers.

Additional datasets are being collected and implemented into the living dataset.

3.2 Data harmonization

All the datasets we obtained have been processed to a standard format and saved in individual NetCDF files. The current harmonization standard follows the format shown in Table 1, including the naming convention, unit, time resolution and aggregate methods. According to the description in Sec. 3.1, all the data were processed and saved as their hourly mean and hourly median values whenever available. Here are some exceptions. The ecosystem fluxes, including CO2 flux, NEE, GPP, were saved directly as half-hourly data. However, NEE2 and GPP2 from SMEAR II were saved as hourly mean data. The precipitation was saved as an hourly sum. The NetCDF file names follow the standard format as <name>_<averaging_type>_<time_period>.nc, where <name> is variable name, <averaging_type> is how the data are averaged with respect to time resolution and aggregate methods (e.g., hourly mean, hourly median, raw, etc.), and <time_period> is the time span of the data. All the datasets are stored in the Allas object storage system in CSC and publicly available. They can be downloaded from this link: "https://a3s.fi/swift/v1/AUTH_52c9f7ef62574ad88073aff57e24d63c/FOCI_datasets/" adding the file names shown in the webpage. These processed datasets should be currently confined to FOCI project. However, towards the end of the project we will negotiate with the data providers if (and under what terms) the whole data set could be applied in further studies.

4. RESULS AND DISCUSSION

A recent analysis on quantifying the biogenic feedbacks in boreal and Amazonian environments was performed by Blichner et al. (2024). The methodology that they deployed enabled us to quantify each of the feedback steps as a derivative, i.e. rate of change of each variable involved in the feedback steps (Figure 3). This allows independent analysis of the sensitivity of each step. The work was supported by the FOCI project. Figure 2 shows the schematic approach utilized in the study. In the changing climate, temperature increases, and this leads to elevated biogenic volatile organic compound emissions and associated increase in biogenic organic aerosol mass concentrations. The general feature of organic aerosol mass increase was shown already by Paasonen et al. (2013). Yli-Juuti et al. (2021) studied separately cold and warm summers in boreal forest and showed that the warmer summers will lead to increased organic aerosol mass concentrations.

This step from biogenic emissions to organic aerosol mass concentrations was further solidified by Biogenic Aerosols – Effects on Clouds and Climate (BAECC, Petäjä et al. 2016) data in Petäjä et al. (2022), which explored the connection between time-over-land (a parameter that describes the travel

time over the boreal environment before sampling at a fixed ground site). Initially clean Arctic air masses were transformed into continental airmasses with a dynamically variable aerosol number and mass concentrations. The driving factor for this change was the biogenic emissions, their oxidation in the gas phase and partitioning into the aerosol phase during transport. Räty et al. (2022) further explored the phenomenon with 10 years of observational data. The conclusions remained the same, the slower air masses will warm up and the biogenic aerosol mass concentrations tend to increase.

The work by Blichner et al. (2024) tried simplifying the connection between the increased organic aerosol mass and the properties of clouds. The results were explored with the use of SMEAR II and ATTO observational data but also with data from a suite of Earth System Models (NorESM, ECHAM-SALSA, EC-EARTH, UKESM). They showed that the increase in aerosol mass concentration led to a change in cloud radiative properties and tended to cool down the climate and that this feature is prevalent both in boreal environment as well as in the Amazon rainforest environment (see Figure 4 in Blichner et al., 2024). However, the link between the organic aerosol mass and the cloud properties varied significantly between the models. This was largely due to the diverse impact of OA mass increase on particle number and size in different models, which lead to highly varying impacts of OA on the feedback strength (Figure 3). These results indicate the need for a thorough and detailed analysis on the connections between SOA mass formation, evolution of particle number size distribution, CCN concentrations and cloud droplet properties at multiple and diverse environments.

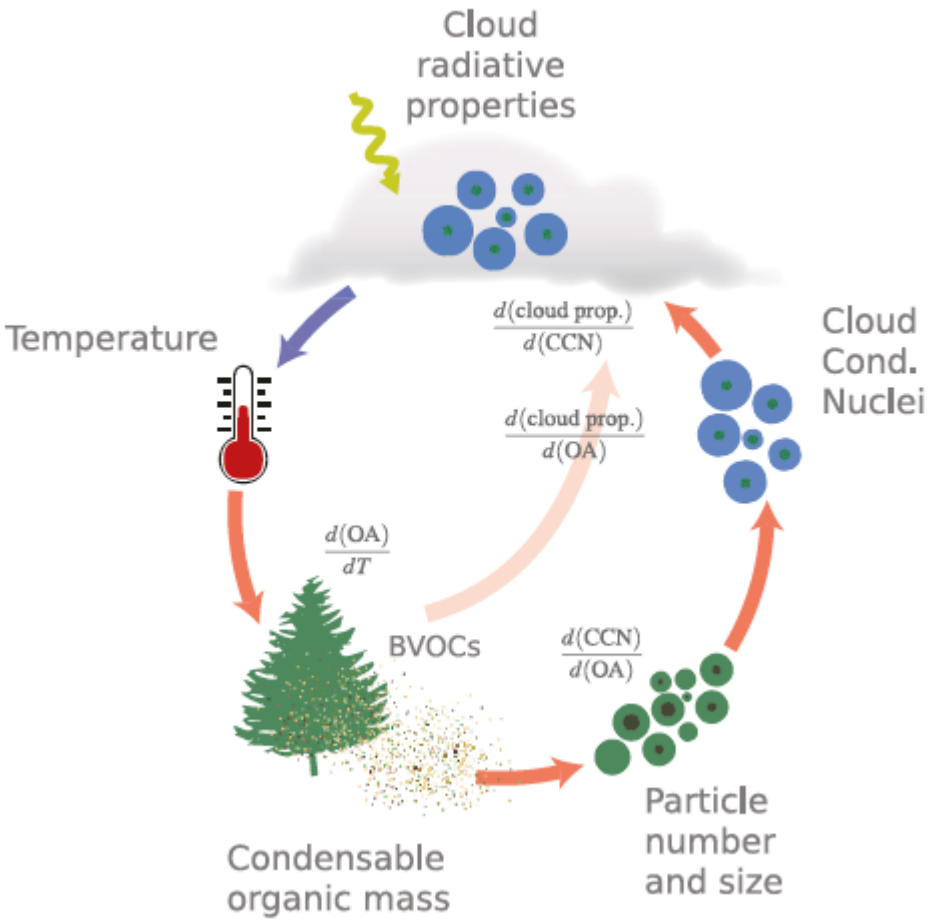

Figure 3: *Analysis of biogenic feedbacks in boreal and Amazon environments utilizing the data from observations as well as Earth System modeling data. The red arrows indicate positive feedback invigorating*

the change, while the blue arrow indicates a negative feedback inflecting a controlling feature to the change. Figure from Blichner et al. (2024).

Paasonen et al. (2016) showed that the level of anthropogenic emissions defines the scale of the biogenic feedback loops described in Figure 1. The feedbacks are effective only when the particle growth by biogenic SOA formation exceeds the anthropogenic direct particle emissions in producing particles large enough to act as CCN and/or influence radiative transfer. On the other hand, the formation of the nucleation mode particles that grow to CCN-sizes via biogenic SOA formation is also an interplay between anthropogenic and biogenic emissions. Recently, Garmash et al. (2024) found out that new particle formation events in Boreal Russia are more intense, when both sulfuric acid concentration, originating from anthropogenic sources, and BVOC concentrations are high. Understanding the anthropogenic two-way impacts on the feedback loop strength requires more analysis on data sets with varying influence of anthropogenic emissions, which is the goal of WP2 in FOCI.

5. OUTLOOK

Here we summarized the recent work done in the analysis of biogenic feedbacks in the climate system based on data sets collected in WP 2 as well as published recently in the literature. The analysis work was supported by the FOCI-project.

The work of WP 2 will continue by expanding the observational data set presented here. The data set will be utilized in the development of growth rate analysis tool and further data analysis regarding feedbacks.

6. REFERENCES

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