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HELSINGFORS UNIVERSITET
UNIVERSITY OF HELSINKI

INAR Institute for Atmospheric and Earth System Research

SMEAR

STATION FOR MEASURING
EARTH SURFACE – ATMOSPHERE
RELATIONS

SMEAR CONCEPT

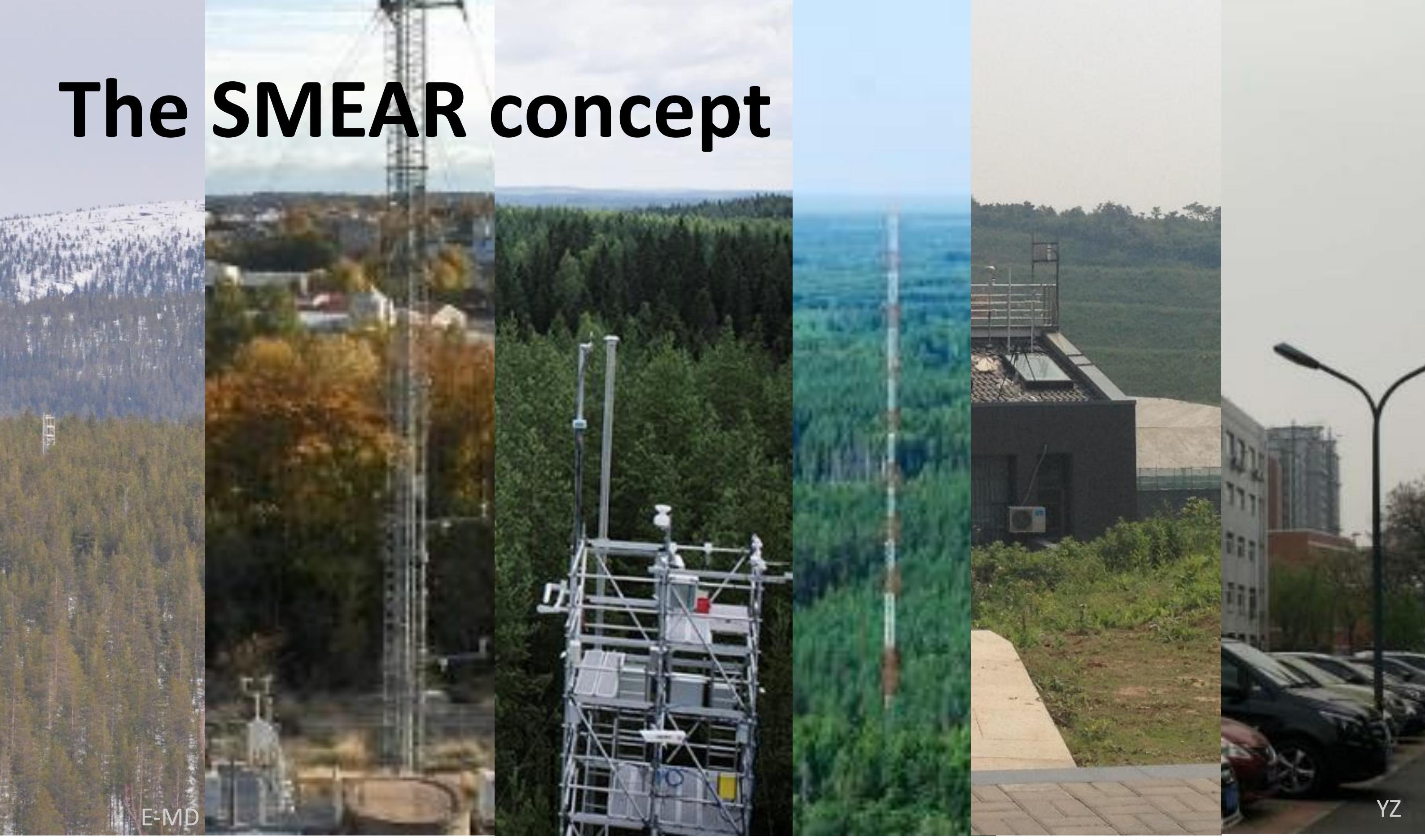
Flagship stations SMEAR II
Hyytiälä, Finland 1995-

First edition, June 2018

Photo Credits: as marked on the lower right corner of the photo. JA(Juho Aalto); ML (Mati Loponen); NS(Nina Sarnela); YZ (Ying Zhou); HJ (Heikki Junninen); SH (Sami Haapanala); NA (Nuria Altimir); E-MD(Ella-Maria Duplissy); K-ME (Kukka-Maaria Erkkilä); NN (Nikko Nappu).

Layout and drawings: Nuria Altimir

The SMEAR concept



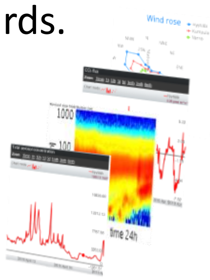
SMEAR I Värriö Lapland 1990- | SMEAR III urban Helsinki 2004- | SMEAR IV Puijo 2008- | SMEAR-Estonia Järviselja 2010- | SORPES station Nanjing China | SMEAR-BUCT Beijing China 2018-

SMEAR Measurement Concept can be applied at any location to produces comprehensive, simultaneous measurements on atmosphere, Earth surface and biosphere, covering meteorology, atmospheric composition and fluxes, as well as ecosystem variables. Forest, lake, peatland, marine coastal and urban are examples of Earth surfaces where SMEAR concept is currently used. The SMEAR measuring concept is underlining the importance of the following:

- for the comprehensive atmospheric monitoring we need both In-situ observations and ground base remote sensing measurements
- Open access, open data, data flows are fundamental principles of the SMEAR concept
- Contributions to several European Strategy Forum for Research Infrastructures (ESFRI)
- Crucial component of the SMEAR concept are the standardized ICOS, ACTRIS, LTER/AnaEE measurements

The Flagship Station SMEAR II and the sister Urban station SMEAR III are ideal examples of the SMEAR measurement concept.

University of Helsinki, Institute for Atmospheric and Earth System Research (INAR), together with SMEAR Ltd. are providing **expert and consultant services** to design tailored measurement setups and technical instrument installation including data flows to create or update your station with SMEAR standards.



Why SMEAR ?

- Science-based, independent data on quality of the environment
- Capacity for monitoring regional and long-range, transboundary pollution transport
- A quantitative budget of GHG (CO_2, N_2O and CH_4) sinks and sources and their development over time
- Data on ecosystem processes incl. water use efficiency, photosynthesis and carbon allocation
- Enables identification of particular pollutant sources (e.g. individual ship, individual manufacturing plant)
- An early warning system and mechanism for safe operation / evacuation in the case of industrial accidents
- Improved use of existing infrastructures and institutional resources by modernizing monitoring methodologies

Flagship station SMEAR II

N 61° 50.845', E 24° 17.686', altitude 180 m a.s.l.

The SMEAR II (Station for Measuring Ecosystem – Atmosphere Relations) in Hyytiälä, Finland, represents the most advanced station of the SMEAR concept. SMEAR II station is carrying out measurements 24/7 on 1200 parameters on different ecosystems: boreal forest, wetland and lakes.

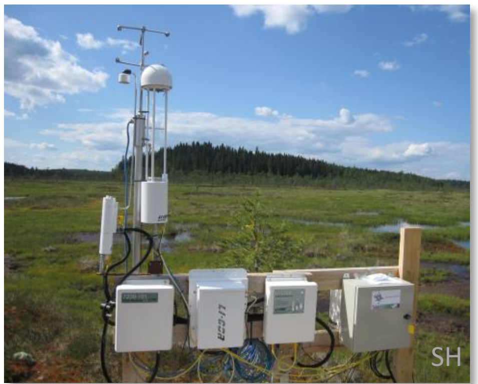
SMEAR II is contributing to several global Earth Observation systems and networks such as WMO GAW, GEO-GEOSS, FluxNet, AERONET and SolRad-Net, and to the European Research Infrastructures such as ICOS, ACTRIS, AnaEE and eLTER.

Instrument cottage

Aerosols

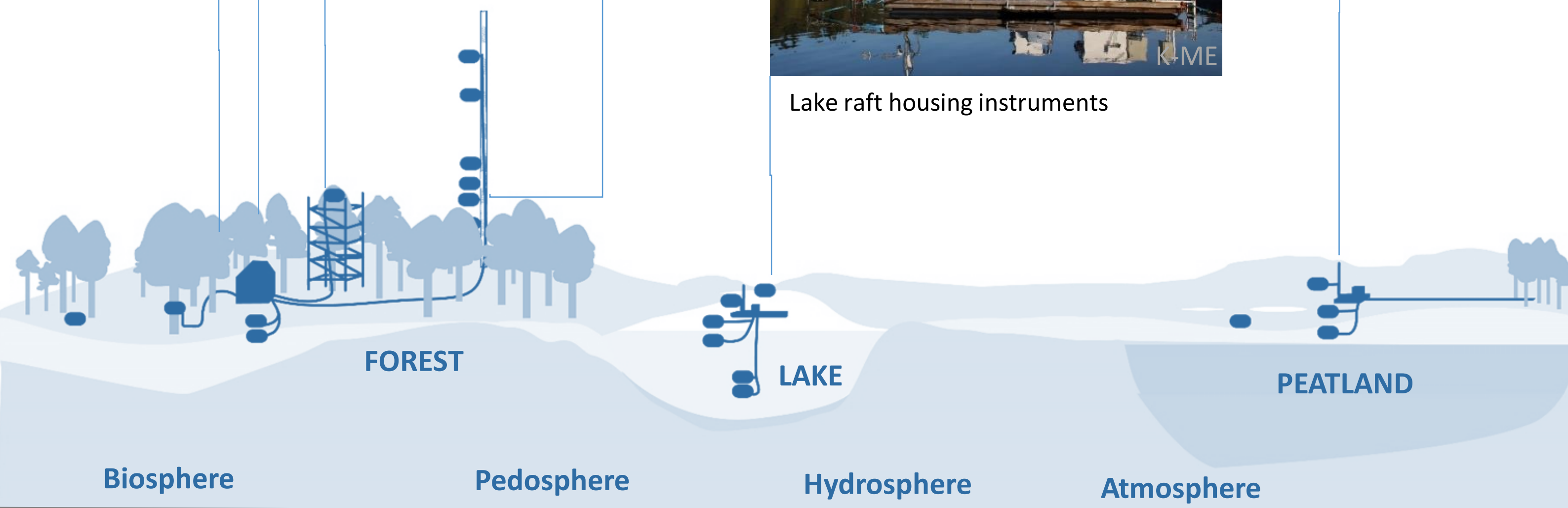
Shoot-level flux chamber

Instruments on mast (130 m) and towers to measure at different heights



Eddy Covariance systems

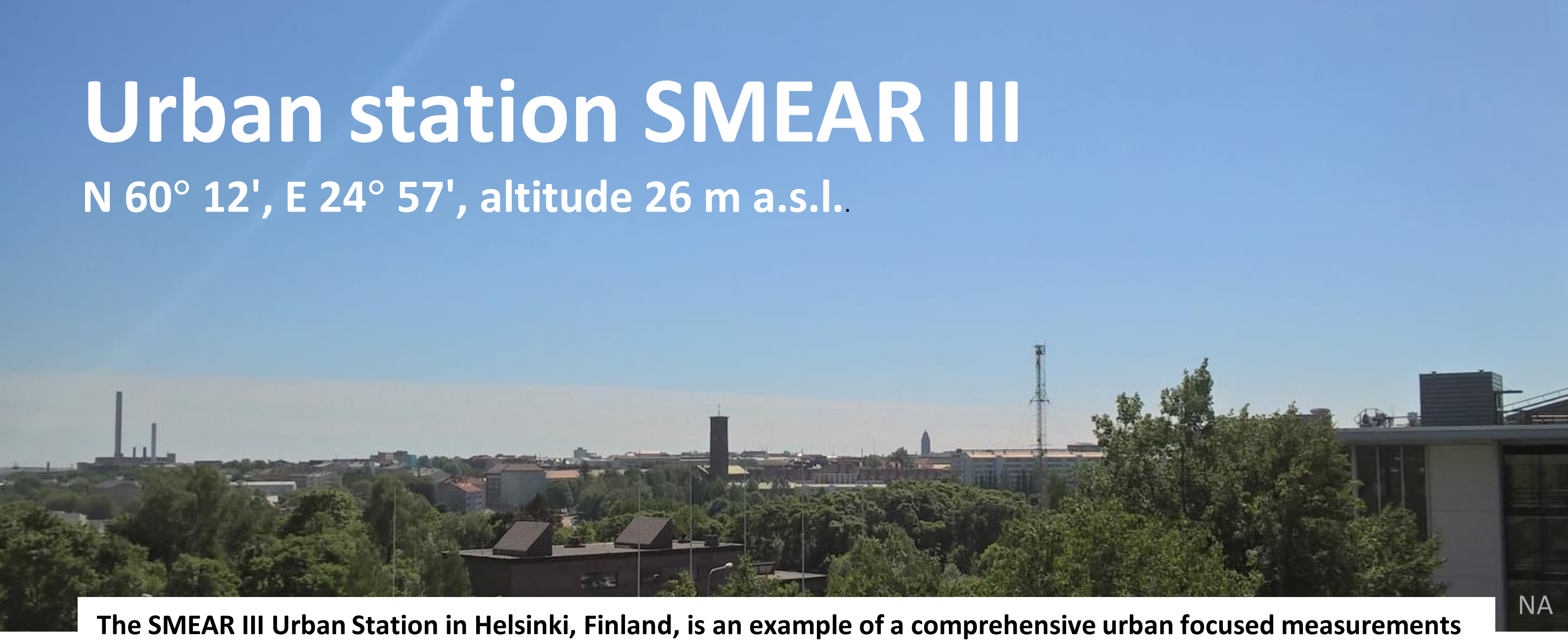
Lake raft housing instruments



* WMO GAW World Meteorological Organization - The Global Atmosphere Watch , The intergovernmental Group on Earth Observations (GEO) - a Global Earth Observation System of Systems (GEOSS), ICOS (Integrated Carbon Observation System), ACTRIS (Aerosols, Clouds, and Trace gases Research Infrastructure), AnaEE (Infrastructure for Analysis and Experimentation on Ecosystems), eLTER (Integrated European Long-term Ecosystem)

Urban station SMEAR III

N 60° 12', E 24° 57', altitude 26 m a.s.l..

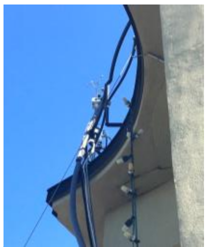


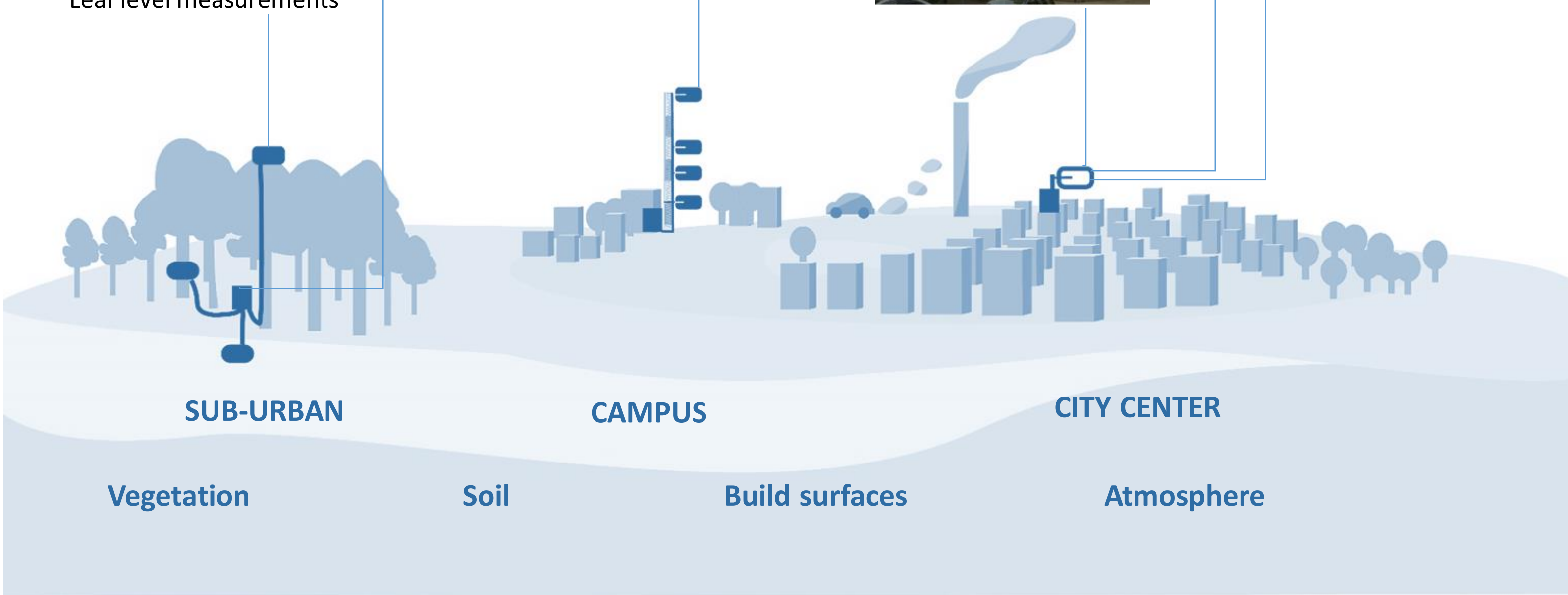
The SMEAR III Urban Station in Helsinki, Finland, is an example of a comprehensive urban focused measurements station. SMEAR III station is carrying out measurements 24/7 at different urbanization levels: city centre and campus, and can be complemented with sub-urban locations.

Measurements at different heights on a mast (31 m)

Eddy Covariance systems measuring fluxes of momentum, heat, water, CO_2 and aerosol particles.

Leaf level measurements





SMEAR measurements and new initiatives in different environments

Show cases

INAR Institute is actively participating Polar expeditions such as Villum / Station Nord Greenland, Ny Ålesund, Svalbard, Aboa, Antarctica and to upcoming MOSAIC in September 2019 – October 2020. We are studying

- detailed mechanisms of secondary new particle formation and related chemistry via direct measurement of aerosol precursor vapors, cluster chemical composition, physical properties of aerosol, etc.
- the consequences of sea ice loss and climate change to aerosol and CCN system via effects to sea- and ice-borne phytoplankton ecosystems.
- the effects of increasing human activities and air pollution to regional atmospheric system.

INAR Institute is as a partner in a EU Horizon2020 Twinning project together with The Cyprus Institute (CyI), Max Planck Institute for Chemistry (MPIC) and Commissariat à l'Energie Atomique (CEA), project budget of the 1st stage is 1 million €. Our main role in the twinning project is to upgrade and design the existing Agia Marina Xyliatou station of Cyprus Institute in The Eastern Mediterranean and Middle East (EMME) region, towards SMEAR station.

The new, 2018- measurement site in China based on SMEAR blocks is located on a rooftop of a campus building at Beijing University of Chemical Technology (BUCT) in the western part of Beijing. Known as HAZE-Beijing, this station is close to fresh traffic emissions and also surrounded by residential areas. We are expecting new results on:

- New particle formation and Haze events
- Gas characteristics of NPF and Haze events
- Aerosol Dynamics
- Meteorological Conditions

The SMEAR blocks can be tailored to different surfaces. For example, the ecosystem instrument block can be tailored to measure biological activity, fluxes and energy flows in different ecosystems such as forests, wetlands, but also for the crop lands. The first "proof of concept" on the crop land based on SMEAR measurements is underway.

Upgrading your station to SMEAR

COMPONENTS

SUPPORTING INFRASTRUCTURE

Elements that are not purely instrumental but make feasible the existence of a measuring site. They include basic infrastructures: roads, access to electricity and communication technology, heating, and other civil constructions. The housing elements for instruments and research activities are also part of the supporting infrastructure: buildings, cottages, containers, scaffolding towers and accesses. Upgrading your station will make use of the available supporting infrastructure and complement it if needed.

INSTRUMENTS

Upgrading of stations is conceived in a **modular structure.** The capacity and the installation of the SMEAR modules is flexible and is designed based on local requirements of the site, both adapting to the existing infrastructures and adapting to the type of system to be measured. A **topical module** is an ideal set of instruments for the quantification of a particular phenomenon. You may upgrade your station or establish a new station by installing a SMEAR topical module or standardized instruments. Either way your station will contribute to the SMEAR measurement concept and be also part of the standardized data formats of international / European research infrastructures.

STAFF TRAINING

In the ideal situation the daily running and maintenance of the stations are done by local staff. We help improving your technical and scientific skills by providing: • On-site training of local staff during installations • Dedicated courses and training at the flagship station SMEAR II in Finland • Training in data analysis • Scientific education via graduate and doctoral studies.

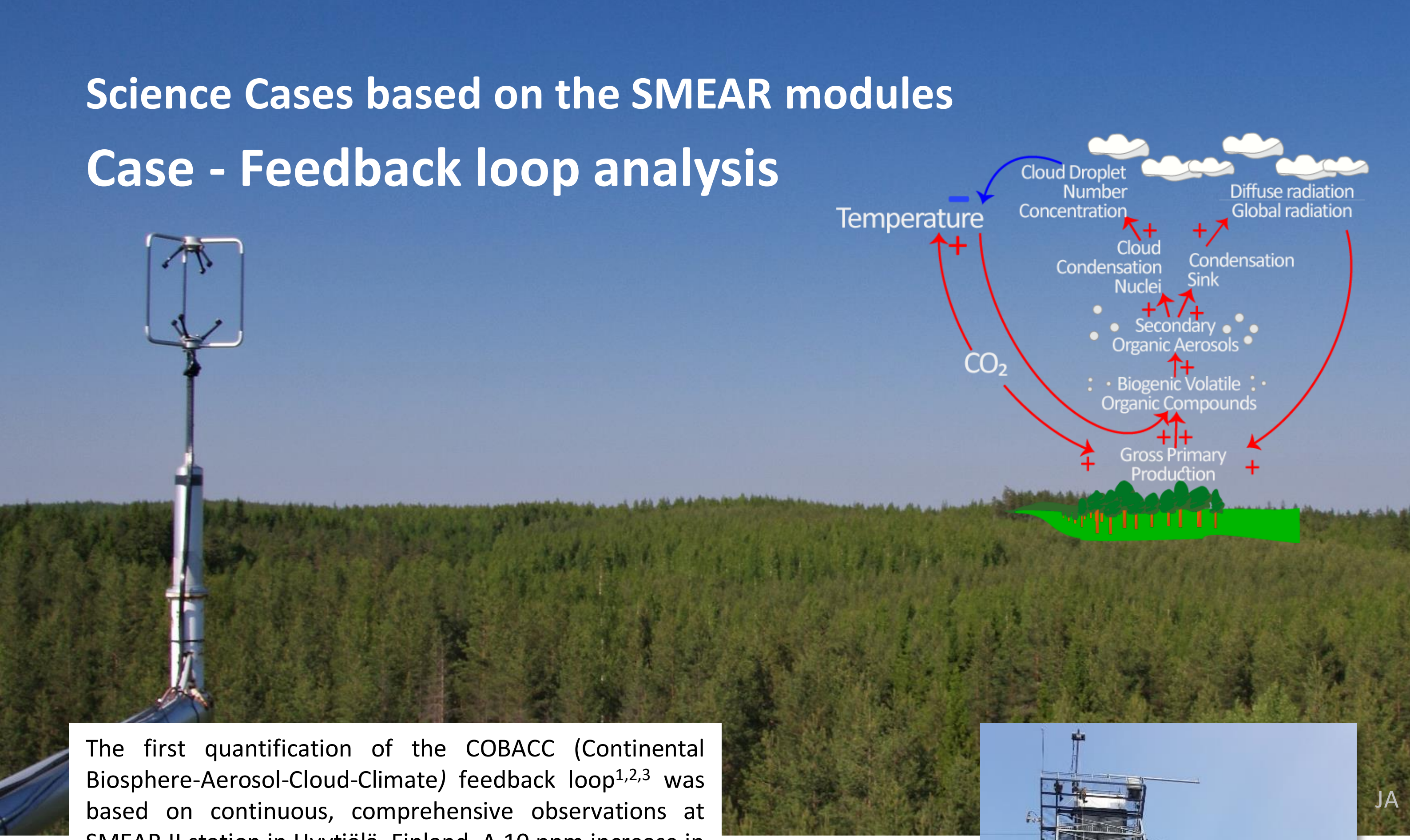
OPEN DATA AND DATA FLOWS

As a part of the instrument installation we set up data processing system from raw data to data products. **Data curation** is designed as an essential part of the SMEAR concept. It includes: **.** Formal documentation • Well organized and safe data storage and user interfaces • Relational database collects processed end-user data, accessible from anywhere via browser-based human interface and via Application Programming Interface (API) that allows scripted retrieval of data. • Metadata catalogues providing visibility and discoverability to the data • All data attached with unique persistent identifiers (PID), which identify the data and metadata and allow citations for the data. • Data from SMEAR stations are directly available at http://avaa.tdata.fi/web/smart/smear, the AVAA portal and API.

Data licensing. The defining principle of data licensing is "free use of data with acknowledgement of the original data providers". The current SMEAR data license is Creative Commons 4.0 Attribution (CC 4.0 BY) with additional request of fair scientific use: co-authorship in scientific publication should be offered to the original data providers whenever substantial use is made of the data or intellectual input required for interpreting the data.

Science Cases based on the SMEAR modules

Case - Feedback loop analysis



The first quantification of the COBACC (Continental Biosphere-Aerosol-Cloud-Climate*)* feedback loop[1,2,3] was based on continuous, comprehensive observations at SMEAR II station in Hyytiälä, Finland. A 10 ppm increase in atmospheric CO_2 concentration leads to a significant increase in both carbon sink and aerosol source. These effects operate through changes in gross primary production, volatile organic compound (VOC) emissions and secondary aerosol formation associated with atmospheric oxidation of VOCs. The feedback loop demonstrates the importance of biospheric processes not only for the carbon and aerosol budgets, but also for the whole climate system. The COBACC feedback suppresses global warming, proving a window of opportunity to reduce global carbon emissions. This needs to be quantified in a global perspective. The strength of the COBACC feedback is tightly connected with biospheric functions, including the observed, yet poorly-understood Arctic greening and other vegetation changes currently taking place in boreal and Arctic environments. More knowledge is needed to understand, how the COBACC feedback loop will develop in the future.

Instruments needed for Feedback loop

Variables	Instruments
Fluxes of CO_2, H_2O, CO, CH_4	Picarro + 3D anemometer
Concentration of VOCs	PTRMS and/or GC-MS
Aerosol number size distribution	DMPS
	NAIS
Meteorological station including radiation (total and diffuse)+ceilometer	
Mast and cottage	
Data	

[1] Kulmala et al. (2004) A new feedback mechanism linking forests, aerosols, and climate, *Atmos. Chem. Phys. 4, 557-562*. [2] Kulmala et al. (2014) CO_2-induced terrestrial climate feedback mechanism: From carbon sink to aerosol source and back, *Boreal Environ. Res. 19, 122-131*. [3] Paasonen et al. (2013) Warming-induced increase in aerosol number concentration likely to moderate climate change, *Nature Geosci. 6, 438-442*.

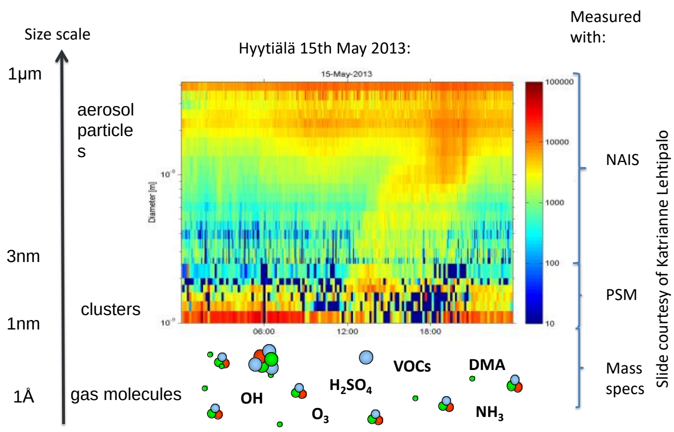
Case - New particle formation

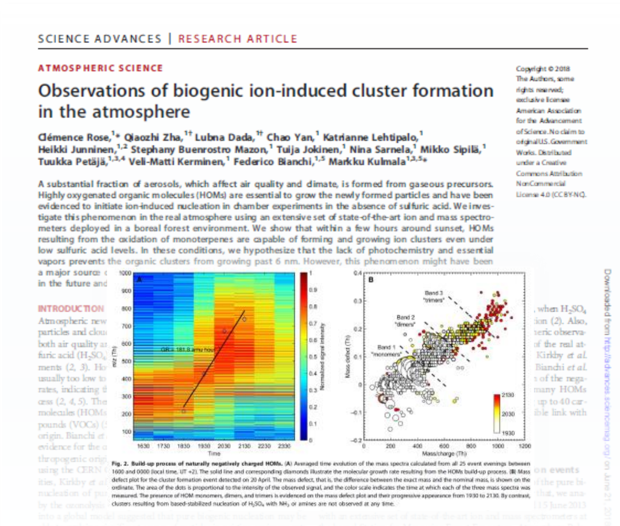
Gas-to-particle conversion (GTP) is a key phenomenon for our understanding of processes, interactions and feedbacks between atmospheric chemistry and physics. By producing new aerosol particles and secondary particulate matter, GTP modifies the number concentration, size distribution, chemical composition and mass loading of atmospheric aerosol particle populations, thereby having close associations with both air quality and climate. The GTP taking place below particle sizes of a few nm, termed nano-GTP here, is of special interest because it dictates the contribution of new particle formation (NPF) to the atmospheric aerosol number load. The formation of critical-size molecular clusters has traditionally been called nucleation, and the research has been focused on:

- identifying the vapors participating in atmospheric nucleation and the nucleation mechanism
- developing mathematical frameworks to describe the nucleation process
- investigating whether atmospheric ions participate in nucleation

Until recently, much less effort has been devoted to exploring the gas-phase chemistry responsible for the production of nucleating and condensing vapors. The main reason has been that sulfuric acid, produced via the gas-phase SO_2 + OH reaction, was long thought to be the sole important trace gas in this respect. However, several recent findings have shown that this is not necessarily the case[2,3]. Instruments, such as the Particle Size Magnifier[4] (PSM) Chemical Ionisation Atmospheric Pressure interface Time–of-Flight mass spectrometer[5] (CI-APi-TOF) and Neutral cluster and Air Ion Spectrometer[6] (NAIS), have proven to be very effective in both laboratory[3]and atmospheric[7] investigations. In order to truly be able to verify and quantify the different steps in nano-GTP, we must develop our instrumentation even further and apply them in various environments from well-controlled chamber facilities to remote and hard-to-access sites around the planet.

Discovering the world below 3 nm





SCIENCE ADVANCES | RESEARCH ARTICLE

ATMOSPHERIC SCIENCE

Observations of biogenic ion-induced cluster formation in the atmosphere

Clémence Rose, Qiaozhi Zha, Lubna Dada, Chao Yan, Katrianne Lehtipalo, Heikki Junninen, Stephany Buenrostro Mazon, Tuija Jokinen, Nina Sarnela, Mikko Sipilä, Tuukka Petäjä, Veli-Matti Kerminen, Federico Bianchi, Markku Kulmala

A substantial fraction of aerosols, which affect air quality and climate, is formed from gaseous precursors. Highly oxygenated organic molecules (HOMs) are essential to grow the newly formed particles and have been evidenced to initiate ion-induced nucleation in chamber experiments in the absence of sulfuric acid. We investigate this phenomenon in the real atmosphere using an extensive set of state-of-the-art ion and mass spectrometers deployed in a boreal forest environment. We show that within a few hours around sunset, HOMs resulting from the oxidation of monoterpenes are capable of forming and growing ion clusters even under low sulfuric acid levels. In these conditions, we hypothesize that the lack of photochemistry and essential vapors prevents the organic clusters from growing past 6 nm. However, this phenomenon might have been a major source ...

INTRODUCTION

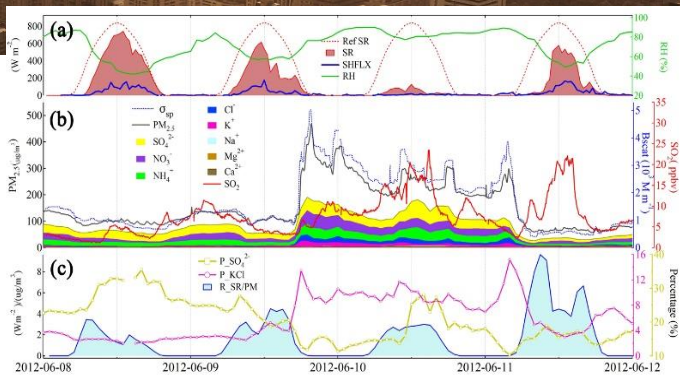
Fig. 2. Build-up process of naturally negatively charged HOMs.

Variables	Instruments
Clusters	PSM
	NAIS
Bigger particles	CI-APi-ToF
	DMPS
	APS
Meteorology	
Trace Gases	

[1] Friedlander, 1977. [2] Bianchi F. et al. (2016) New particle formation in the free troposphere: A question of chemistry and timing. *Science, 352, 1109–1112.* [3] Kirkby J. et al. (2016) Ion-induced nucleation of pure biogenic particles. *Nature, 533, 521–526.* [4] Vanhanen, J., et al., (2011). Particle size magnifier for nano-CN detection, *Aerosol Sci. Tech., 45, 533–542.* [5] Jokinen, T. et al. (2012) Atmospheric sulfuric acid and neutral cluster measurements using CI-Api-TOF, Atmos. Chem. Phys. 12, 4117-4125. [6] Kulmala, M., et al. (2007). Toward direct measurement of atmospheric nucleation, *Science, 318, 89–92.* [7] Kulmala, M. et al. (2013) Direct observations of atmospheric nucleation, Science 339, 943-946.

Case - Air Quality

Comprehensive, multi pollutant approach to air quality. The rapid, large-scale urbanization and industrialization of the developing world has led to severe deterioration of air quality, threatening the health of hundreds of millions of people[1,2,3] In addition to premature mortality and other health effects, air pollution causes major problems to the environment and the economy by severely decreasing agricultural and industrial productivity. As a remedy to air pollution, we have recently drafted a roadmap for a holistic multi-pollutant approach[2], which is expected to pave the way for a pioneering, long-lasting and cost-effective strategy for solutions to air-pollution problems in large urban regions and particularly in Megacities. Furthermore, advances in our theoretical understanding have already revealed how elevated pollution affects weather conditions[4], and how it decreases atmospheric turbulence and mixing, reducing the boundary layer height[5] and thus further elevating pollution levels[6,7] including production of secondary aerosols[8].



(a) Solar radiation, sensible heat flux and relative humidity recorded at a urban flux site of SORPES. (b) PM2.5 mass, water-soluble ions, aerosol scattering coefficient (at 650nm) and SO2 measured at the SORPES Xianlin site. (c) Proportions of sulfate and KCl in the total PM2.5 mass and the ratio of "blocked" solar radiation over the PM2.5 mass concentrations at the Xianlin Site (Ding et al. 2013).


COMMENT

China's choking cocktail

Cleaning up city and indoor air will require a deeper understanding of the unprecedented chemical reactions between pollutants, says Markku Kulmala.

Instruments needed for Air Quality

Option 1
Variables and instruments
PM 2.5 and 10
Trace gases (Thermo package) NO_x, CO, O_3, SO_2 + Calibrations
BC

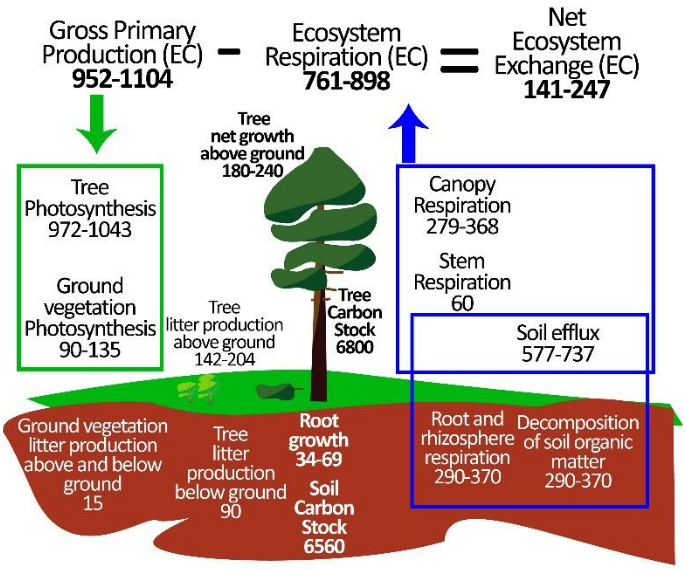
Option 2
Variables and instruments
Number size distribution
Aerosol optics, Nefelometer
ACSM
MARGA

[1] Lelieveld et al. (2015) The contribution of outdoor air pollution sources to premature mortality on a global scale. *Nature, 525, 367–371.* [2] Kulmala (2015). Atmospheric chemistry: China's choking cocktail. *Nature News 526, 497–499.* [3] Apte et al (2015) Addressing Global Mortality from Ambient $PM_{2.5}$. *Environ. Sci. Technol., 49, 8057–8066.* [4] Ding et al. (2013). Intense atmospheric pollution modifies weather: a case of mixed biomass burning with fossil fuel combustion pollution in eastern China. *Atmos. Chem. Phys., 13, 10545–10554.* [5] Zilitinkevich et al. (2013) A Hierarchy of Energy- and Flux-Budget (EFB) Turbulence Closure Models for Stably-Stratified Geophysical Flows. *Boundary-Layer Meteorol., 146, 341–373.* [6] Ding et al. (2016) Long-term observation of air pollution-weather/climate interactions at the SORPES station: a review and outlook. *Frontiers of Environ Sci & Eng 10, 15.* [7] Petäjä et al. (2016) Enhanced air pollution via aerosol-boundary layer feedback in China, *Sci. Repts., 5, 18998.* [8] Kulmala et al. (2017). Atmospheric gas-to-particle conversion: why NPF events are observed in megacities? *Faraday Disc.. 200, 271-288..*

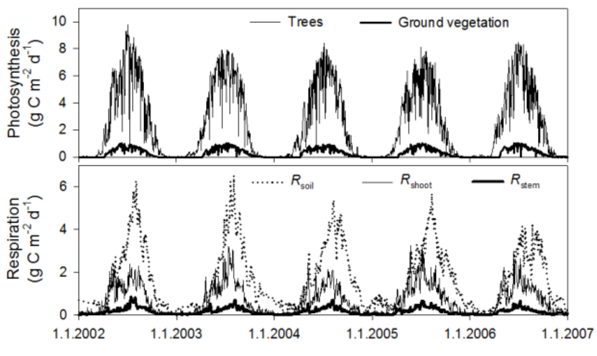
Case – Ecosystem carbon balance

In order to understand the role of ecosystems in climate change, the SMEAR concept includes observations of essential biogeochemical cycles, e.g., carbon, water and nitrogen at several scales. Measurements at SMEAR II are done in a forest stand as well as at a wetland site and on a floating raft in close-by lake. Long-term measurements allow analyses of the pronounced seasonality and the detection of climate-relevant processes like the effect of temperature and precipitation on the biogeochemical cycles. When combined to other GHGs and optical measurements, also the ecosystem energy balance and total GHG budgets can be verified [1,2].

Combination of the ecosystem-scale exchange and detailed measurements of flux partitioning to tree canopy, soil and ground vegetation is a prerequisite for development of process-based models, which can be used in predicting ecosystem functioning in future conditions.



Apportioning the carbon fluxes in the SMEAR II forest stand to canopy, understorey and soil contributions. (Ilvesniemi et al 2009). Values in gC/m^2.



Carbon fluxes (photosynthesis and respiration) of the forest trees, ground vegetation and forest soil over 5 years. (Kolari et al 2009).

Variables	Instruments
Branch-level fluxes of CO_2, H_2O, CO, CH_4	Custom made automated chamber systems
	CO_2/H_2O analysers
	CO_2/H_2O/N_2O/CH_4 analysers
	Custom-made automated sampling control and datalogging
Soil moisture and temperature at 5 depths	
Ancillary measurements	Tower incl. meteorological station
Ecosystem-level fluxes of CO_2, H_2O, CO, CH_4	Eddy/Micrometeorology Module Instruments

[1] Ilvesniemi et al (2009) Long-term measurements of the carbon balance of a boreal Scots pine dominated forest ecossytem. *Boreal Environ. Res. 14:731-753.* [2] Kolari et al (2009) CO_2 exchange and component CO_2 fluxes of a boreal Scots pine forest. *Boreal Environ. Res. 14:761-783.*

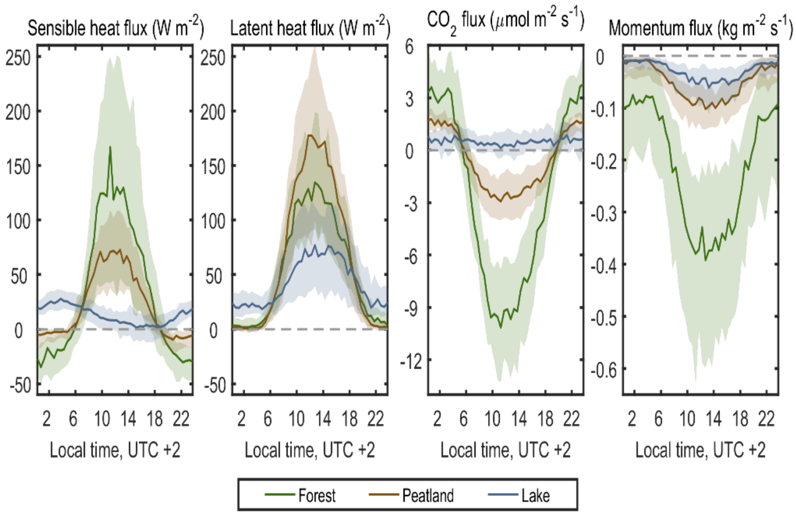
Case – Surface-atmosphere exchange of energy and greenhouse gases

NN

The coupling of the Earth's surface and the overlying atmosphere through mass and energy fluxes has an important role in atmospheric chemistry and physics in addition to boundary layer meteorology and ecosystem research.

Long term and continuous flux observations are crucial in order to increase the fundamental understanding of atmosphere-biosphere coupling for different ecosystems and surfaces and quantifying sources and sinks of greenhouse gases (GHGs) and other trace gases and their seasonal and interannual variations.

Eddy-covariance flux measurements are done at SMEAR II in a forest stand[1,2,3] as well as at nearby Siikaneva peatland[4] and Kuivajärvi lake[5,6]. All the three sites are ICOS ecosystem stations.



Diel patterns of eddy covariance fluxes observed during summer 2016 above SMEAR II pine forest, Siikaneva peatland and lake Kuivajärvi. Positive values indicate emissions to the atmosphere, while negative values indicate ecosystem uptake.

Variables	Instruments
Eddy covariance fluxes of momentum, sensible and latent heat, CO_2, H_2O, CH_4, N_2O, O_3, COS	3D Ultrasonic anemometer + fast response gas analysers
Automated data logging and calibration	Custom-made
Meteorological station (radiation fluxes, air temperature, relative humidity, wind speed and direction, precipitation, etc)	
EddyUH software[7] for data post-processing and flux calculation, footprint and QC/QA.	

[1]Suni et al. (2003) Long-term measurements of surface fluxes above a Scots pine forest in Hyytiälä, southern Finland, 1996-2001. *Boreal Environ.Res*. 8:287-301. [2] Kolari et al (2009) CO2 exchange and component CO2 fluxes of a boreal Scots pine forest. *Boreal Environ.Res.* 14:761-783. [3]Rannik et al (2012) Ozone deposition into a boreal forest over a decade of observations: Evaluating deposition partitioning and driving variables. *Atmospheric Chemistry and Physics* 12:12165-12182. [4]Rinne et al (2007) Annual cycle of methane emission from a boreal fen measured by the eddy covariance technique. *Tellus Ser.B-Chem.Phys.Meteorol*. 59:449-457. [5]Mammarella et al(2015) Carbon dioxide and energy fluxes over a small boreal lake in Southern Finland. *Journal of Geophysical Research: Biogeosciences*, *120*, 1–19. [6]Methane and carbon dioxide fluxes over a lake: comparison between eddy covariance, floating chambers and boundary layer method. *Biogeosciences*, *15*(2), 429-445. 7Mammarella et al. (2016) Quantifying the uncertainty of eddy covariance fluxes due to the use of different software packages and combinations of processing steps in two contrasting ecosystems, *Atmos. Meas. Tech*., 9, 4915-4933.

Customer journey timeline

M 1 — M 3 — M 8 — M 12 — M 18

Engage

Contacting with the INAR Institute SMEAR Team or SMEAR Ltd.

Identification of the primary your interests; main research topics / early warning / etc.

Overview of your existing capacity and expertise

Discussion on optimum instrument / SMEAR block

Budget planning

Data exploitation plan

Plan

Tailored upgrade and capacity building plan

Optimized instrumentation selection

Purchase of equipment

Data user rights

Timing and schedules

Install

Instrument installation

Data integration to the coordinated SMEAR frameworks

SMEAR observation network certificate

Contracts on payments and other relevant issues

Use

Station in operation

Standard SMEAR data outputs

Specialized data products

Specialized use cases: research / early warning systems / environmental monitoring /

Share

Data sharing

International collaboration

SMEAR network activities

Results dissemination

Interactions with the stakeholders

Further capacity building

Further upgrading to the next SMEAR level

SMEAR

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Towards coordinated continuous comprehensive Global Earth Observatory

JA