Annual Report 2017

Contents

Christine Forsetlund Solbakken, editor.
Ingunn Trones, Sonja Grossberndt and Finn Bjørklid; contributions and adaptions.

Front page: Control of an Innosense micro sensor placed at Nationaltheatret station in Oslo.
Photo: Ingunn Trones & Finn Bjørklid, NILU.

MILJØMERKET 241 013 TRYKKSAK

New strategy – an institute in rapid development

In December, NILU's board adopted a new strategy for 2018-2022. NILU will continue to be a world leader within atmospheric and climate research on both regional and global scales, urban air quality and research on environmental contaminants. However, we will also clarify and increase our focus on air quality and health research, while emphasising sustainable environmental and climate solutions, both for the public and private sectors. We will also contribute with expertise in digitalisation and further develop our innovation efforts.

NILU actively invests within the Arctic and Antarctica with full-time atmospheric monitoring linked to excellent research. The Zeppelin observatory is a central monitoring observatory for the atmosphere, led by NILU. The government of Norway has also established SIOS (Svalbard Integrated Arctic Earth Observing System) with NILU as a member, and the Zeppelin observatory is part of this infrastructure. In Tromsø, Fram II is about to take shape, and NILU is committed to delivering advanced analyses from our new laboratory with cleanroom facilities centrally located in the new building.

Norway is undergoing a comprehensive transformation process in both the public and private sectors. Productivity Commission reports are followed up with sectoral reviews, and we are expecting major changes in the coming years. It is important for NILU to prepare a good strategy for this change, and we are in good dialogue with our ministry.

Climate

NILU has a number of activities on the climate system and conducts leading research on climate drivers (short and long lived) and geophysical processes. Since 2015, basic research on turbulence has been a key issue, and there is further focus on atmospheric dispersal processes. In 2017, NILU wrote several important publications on the topics of atmospheric methane and CO_2. There was also a great deal of activity aimed at developing research infrastructures that support climate research (ICOS, SIOS, INES and ACTRIS). Another aim is to establish a new center for studies of atmospheric water transport.

Horizon 2020

The EU Framework Programme (H2020) has many new announcements in 2018 that are relevant to NILU. By the end of 2017, NILU participated in 13 H2020 projects. Norway is investing heavily in EU research, and the Research Council's statistics show very good H2020 results for NILU. Despite hard competition, NILU has done well.

Innovation

Innovation is an interdisciplinary activity at NILU, and contributes to a number of areas through the generation of ideas and contributions to projects. NILU further safeguards its societal relevance by being active with new and exciting spin-off companies. Kjeller innovation, together with NILU and the other institutes at Kjeller, is working to float a major investment fund for young companies and startups. This will be important when promulgating the institute's many ideas to new companies and future customers of NILU's research.

In this annual report, we invite you to read about our many exciting new initiatives and excellent research — good reading!

Kari Nygaard
Managing Director

Photo: Ingunn Tronerud, NILU.

Research for a clean atmosphere

Photo: Claudia Hak, NILU.

NILU – Norwegian Institute for Air Research was established as a foundation in 1969. Our research aims to increase the understanding of processes and effects related to our core business areas: atmospheric composition, climate change, air quality and hazardous substances.

The institute holds a strong position both nationally and internationally, and we are among the leading professionals in the world within our core research fields. We provide services closely linked to our research, and have extensive experience in coordinating national and international research projects. Our key clients include the EU, the Research Council of Norway, industry, and both central and local authorities.

NILU's departments

NILU's research has a wide range, and explores most aspects of what affects the atmosphere, environment and climate. The institute's composition, represented by our various departments, reflects this:

The Atmosphere and Climate Department does research on air pollution at regional (European) and global levels, greenhouse gases and climate drivers, volcanic ash transport and dispersion, ozone and UV. The department also conducts extensive international cooperation and serves as a data centre for a variety of measurement and research programmes.

The Urban Environment and Industry Department conducts research on issues regarding local and regional air pollution. Their research ranges from development of air quality management systems in large cities, to developing systems that include greenhouse gas emission and local air pollution. In addition, the department plays a leading role in Norwegian environmental monitoring and research on industrial emissions.

The Department of Environmental Impacts and Sustainability works primarily with exposure and effect studies, cost-benefit analysis and socio-economic studies on the effects of pollution on the environment. The department is particularly involved in projects focusing on European coastal zones.

The Environmental Chemistry department does research on new and established pollutants, and has expertise in all types of environmental samples from air, water and sediment to biological material. The department has a particular focus on contaminants in the Arctic, and has two laboratories at its disposal, one at the main office at Kjeller, and one at the Fram Centre in Tromsø.

The Monitoring and Instrumentation Technology Department is responsible for operational management of NILU's field measurements, sampling equipment and instrumentation. The department is also responsible for data collection and quality assurance, in addition to the operation of NILU's observatories in Ny-Ålesund at Svalbard, Queen Maud Land in Antarctica, Birkenes in Southern Norway and Andøya in Northern Norway.

The Software and Hardware Development Department is responsible for development and maintenance of NILU's software and hardware products, project web sites and adaptation of modules and databases.

In addition, NILU includes an **innovation department**, working to ensure the highest possible utility value of the institute's research. The department's primary goal is to make the results from NILU's research available to the public and policy makers, and whenever possible create commercial development from this.

The monitoring station E6-Tiller in Trondheim. This is a traffic-oriented station, measuring particulate matter (PM_{10} and $PM_{2.5}$) and nitrogen dioxide (NO_2). Photo: Claudia Hak, NILU.

How to measure air quality at the ends of the World

From the Zeppelin Observatory at 79 degrees north to Trollhaugen at 72 degrees south – NILU measures air quality at some of the world's most inaccessible places. Why so far away?

Christine F. Solbakken
Head of Communications

– The reason why it is so important to measure air quality in the Arctic and Antarctica is that those are the most vulnerable areas. We see changes there first, senior scientist Chris Lunder from NILU's Department of Monitoring and Instrumentation Technology explains.

"Pre-industrial" air

The Zeppelin Observatory near Ny-Ålesund on Svalbard, and the Trollhaugen Observatory in Queen Maud Land, is where the air is purest in the northern and southern hemisphere, respectively. This means that NILU's scientists can measure air at what they refer to as the "background level". The background level means the lowest level of different particles and gases present in the atmosphere, and it is only measurable in places where human activity does not contribute to local contamination. You find the cleanest air on earth in Antarctica, and from air samples taken there, scientists have the best information to say something about how the formation of particles in the air was before the industrial revolution.

– Knowing the "background level", we can use the air samples to figure out where pollutants come from, and the amounts of pollutants released.

Showing trends over time

Greenhouse gases are mixed into the atmosphere, so there is always a certain "background level" of eg. CO_2 in the air. How much higher levels can get varies from station to station, relative to local emissions and how the emissions are transported through the atmosphere.

– The advantage of remote stations like Zeppelin is that it's easier to see trends over time there, because the variation from month to month is smaller, explains senior scientist Ove Hermansen. – You do not get such extensive fluctuations as monitoring stations in more populated areas may display, such as Mace Head in Ireland and the Jungfraujoch Observatory in Switzerland.

These two European observatories

Trollhaugen Observatory in Antarctica.

Photo: Chris Lunder, NILU.


Zeppelin Observatory at Ny-Ålesund, Svalbard.

Photo: Are Bäcklund, NILU.

are located so that they capture air coming in from the Atlantic Ocean. Air masses from this region are often affected by air from highly populated areas in the United States.

If you want to measure the correct background levels, you need really remote observatories like Mauna Loa in the Pacific, Cape Grim in Tasmania and Ragged Point on Barbados. And the Zeppelin observatory, of course – the best background station in the northern hemisphere.

Control and calibration

For NILU to be able to perform high quality air measurements, it is important that those working at, and near the observatory, do not pollute the measurements. Thus, it is crucial to have control of everything in the immediate vicinity, from material selection at the station to where different sources of pollution, such as cars, are situated. The scientists must be absolutely sure that what they measure are real air samples from the Arctic and Antarctica.

To be able to measure accurately, we need our equipment to be in top shape, Hermansen explains.

– The equipment must be calibrated regularly, and correctly.

How and when such calibration takes place depends on the measurement method and type of instrument. Most instruments are tested using a known air sample, a so-called "standard". In addition, NILU participates in "ring tests". During these, a gas bottle of air is sent from monitoring station to monitoring station across Europe. Each station measures air from the same bottle, and should get exactly the same result.

– This calibration takes place within large networks, explains Hermansen.
– NILU is involved in many different networks, each with its own comparative programmes for instruments and equipment for air sampling. This is not only about measuring accurately, as all measurement stations in a network should measure against the same reference so that the results are comparable.
For particle instruments, there are no similar "standards". Thus, at a few years' intervals, representatives from up to twenty of the measurement stations meet at a calibration center in Europe to compare and check that these instruments measure the same.

Strict routines

To ensure that they measure on the same scale as the other monitoring


The electrical vehicle "Vesla" is used when the scientists visit Trollhaugen.

Photo: Jan Henrik Wasseng, NILU.

stations around the world, Lunder, Hermansen and senior engineer Are Bäcklund spend a lot of time calibrating the instruments. There are strict procedures to follow.

– Each station also has its own procedures, says Bäcklund, – where we go through a variety of different validation protocols for the instruments. In order to meet the quality requirements we must show that we perform the validation properly and on a regular basis.

In addition to validating the instruments, the NILU crew must have full control over pressure, temperature and airflow through the air inlet the instruments are connected to. All measurements must be checked and logged, data transferred to NILU and disseminated to the different monitoring networks NILU is part of.

Besides all this, NILU occasionally gets visits from representatives of the various networks, for example the Global Atmospheric Watch. They use their own instruments to perform control measurements on the instruments at Zeppelin.

Valuable networks

Once a week, Hermansen goes through all the raw data and checks if they are correct. Only after this control, the measurements will be recorded as approved in the database. He also participates in monthly meetings with scientists from other European monitoring stations, where they go through all data plots, recorded calibrations and deviations. The deviations are carefully investigated to reveal the cause and find solutions.

In addition, there are annual European meetings, where scientists meet and present plots from their measurement stations. If there are any discrepancies, these are pointed out and discussed, and if the deviations are not explained, the data from this particular measurement station may be discarded.

– This is how we ensure that all our data are of good quality, explains Hermansen, – and we learn a lot from each other during these discussions. Especially about instrument problems, which can be anything from a small leak to a worn-out pump or a missing gasket.

All three can tell stories about cases where solving an instrument problem has taken days, weeks, even months – and it is in such contexts these networks demonstrate their worth. It gives the scientists the opportunity to learn from others' experiences, and find solutions faster than if they had worked alone.

Norway and NILU in the Polar Regions

All data NILU produces based on monitoring at the observatories are openly available as soon as they are quality assured and handed over to the client. Data from both Zeppelin and Trollhaugen are widely used by both Norwegian and international scientists.

– Zeppelin is much more accessible than Trollhaugen, says Bäcklund. – It is much easier to operate most of our equipment there than at Trollhaugen, for purely logistical reasons.

Crew from the Department of Monitoring and Instrumentation Technology visits the Zeppelin Observatory at least every other month. Trollhaugen, however, is visited once a year. The Antarctic observatory is available only during the southern summer season, as it is only possible to fly to the Troll Station from November to February. Thus, it is a lot more challenging to keep the various instruments in continuous operation there. NILU has monitored air quality at the Zeppelin observatory since 1989 (NILU's very first air measurements on Svalbard were done in Ny-Ålesund in 1974), and in Antarctica since 2007. How did NILU end up measuring air from pole to pole?

– Norway is a polar nation, and NILU is in an outstanding position when it comes to shouldering the responsibility for monitoring the air and atmosphere of the Polar Regions, says Ove Hermansen. – NILU has gained expertise and experience over time, and has earned a good reputation giving us access to the necessary networks. We have shown that NILU delivers quality and we will continue doing just that, he concludes.

The Department of Monitoring and Instrumentation Technology

The Department of Monitoring and Instrumentation Technology (MIT) is responsible for the operations of field measurements made by NILU, in addition to all sampling equipment and instrumentation used in the field. This includes everything from calibration and maintenance of instruments and samplers, to data retrieval and quality assurance of measurement data.

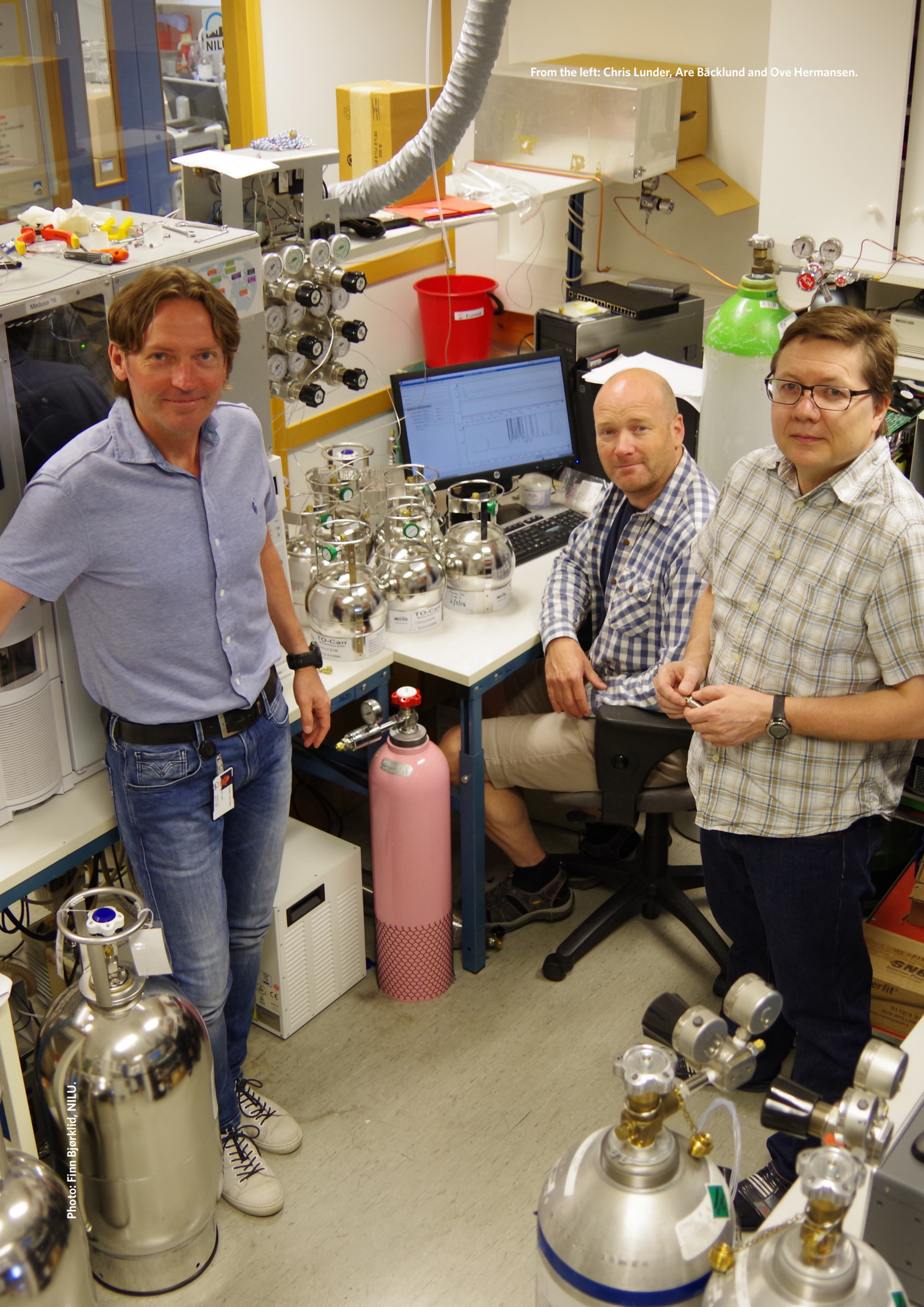
The department is also responsible for the operation of the Zeppelin Observatory in Ny-Ålesund on Svalbard, Trollhaugen in Queen Maud Land, Antarctica, Birkenes in southern Norway and Andøya in northern Norway.

The employees have extensive expertise in quality-controlled operations of monitoring stations and monitoring equipment. In addition, the department contributes to projects and assignments by setting up quality systems for operating air quality measurements for others.

NILU is the National Reference Laboratory for Air Quality, and this work is conducted by MIT. NILU/MIT is also accredited according to NS-EN ISO/IEC17025, with accreditation number TEST 008, for field measurements.

The cableway provides the only access to the Zeppelin Observatory.

Photo: Are Bäcklund, NILU.



From the left: Chris Lunder, Are Bäcklund and Ove Hermansen.

Photo: Finn Bjørklid, NILU.

NILU – hosting global data

Every day, large amounts of data from satellites, monitoring stations, observatories and research campaigns are sent to NILU at Kjeller. In addition to everything else going on here, NILU is also a leading host for data on the composition of the atmosphere, both nationally and internationally.

Christine F. Solbakken
Head of Communications

NILU's prominent role in organising, collecting and storing atmospheric observations was established through the first studies of long-range pollution in the 70's. These data proved that air pollutants could be transported over long distances, and had adverse effects on nature and health. NILU has since been responsible for gathering data from European monitoring stations, and later also globally.

– Since then, NILU has made a name for itself as host for several of the largest European and international research databases, explains senior scientist Ann Mari Fjæraa from NILU's Department for Atmosphere and Climate. – As of today, we collect, organise and make available data on behalf of, among others, the United Nations, the World Meteorological Organization (WMO), several European research infrastructures and the European Space Agency (ESA).

Open data for all

Vital when working with these databases is knowledge of a variety of methods related to measuring, instrumentation and meteorology. There are very stringent requirements for harmonisation of instruments, measurement techniques, data, and for the information accompanying all data recorded in the databases. Such metadata is additional information about the quality and applicability of the measurements contained in the databases. The "EBAS team" at NILU is responsible for all this, in collaboration with data reporters. This database team is a motley crew, with backgrounds in information technology and various sci-

The database team at NILU is a motley crew. From left: Markus Fiebig, Norbert Schmidbauer, Ann Mari Fjæraa, Cathrine Lund Myhre, Wenche Aas, Karl Espen Yttri, Paul Eckhard, Anne-Gunn Hjellbrekke, Sverre Solberg and Kjetil Tørseth. Richard Olav Rud was not present when the photo was taken. Photo: Ingunn Trones, NILU.

Senior scientist Ann Mari Fjæraa.

ence subjects, such as physics, chemistry and meteorology.

– Collecting, systematising and securing data for the future is an important part of the job, explains Fjæraa. – Of equal importance is making the information freely available to anyone who wants access to atmospheric research data.

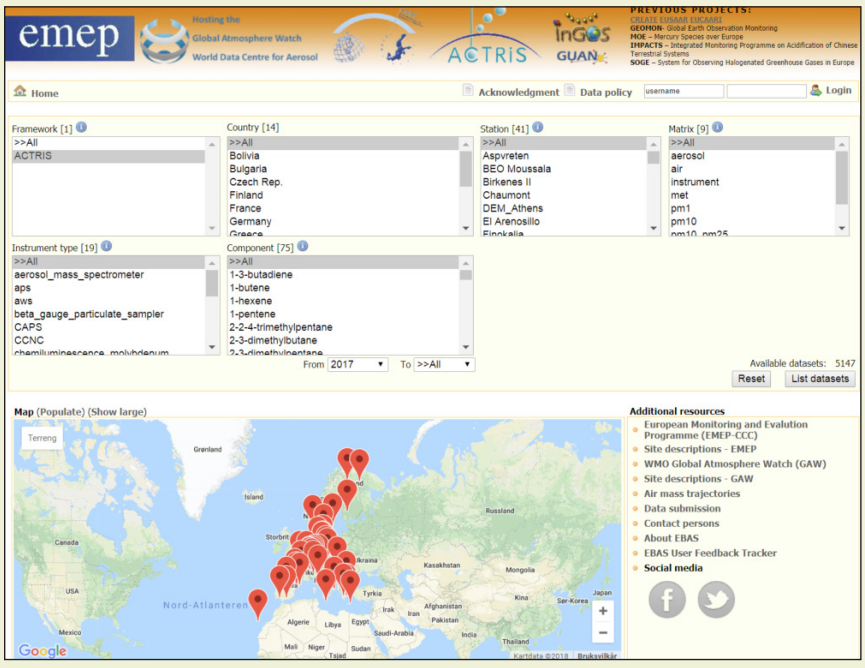
NILU is also data provider to the NorDataNet project (Norwegian Scientific Data Network). NorDataNet provides the scientific community with an integrated, cost-effective and sustainable infrastructure by establishing standards for data documentation, archiving, search and exchange of research data across different computer disciplines and nations.

Data basis for global decisions

The database team also trains data reporters, teaching data formatting, quality assurance and data reporting. In recent years, the databases have evolved from manual data handling to having a high level of operational data flow, where programs and routines are handled by digital routines in near real-time.

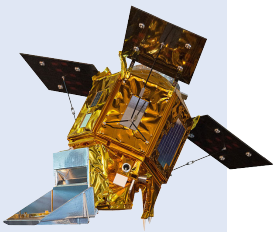
Collections of research data such as those available through NILU's databases are important, independent sources of information. Scientists from all over the world use them to e.g. develop global and regional trends, test models and assess changes in atmospheric parameters over a long period of time. The information from these databases is also important because it forms the basis for international cooperation and policy design for emission reductions on a global level.

– An example of such an important and central database is the EBAS database, explains Fjæraa. – It is built on data collected in connection with a number of projects and monitoring programmes for air quality measurement dating back to the 1970s. NILU still manages the database, and we are responsible for all quality assurance of the data.



Screenshot from the EBAS database, hosted by NILU.

The databases at NILU



The most comprehensive database NILU is responsible for is **EBAS**. In this database you will find observation data on atmospheric chemical composition and physical properties from a variety of national and international research projects and monitoring programmes, such as ACTRIS, AMAP, EMEP, GAW, HELCOM, MOCA and, of course, NILU.

In addition, NILU has been hosting the European Space Agency (ESA) database, **EVDC**, since the beginning of the 2000s. The EVDC database is used to store, quality assure and exchange atmospheric data from earth observation satellites and the data to validate these, i.e. Cal/Val data (calibration and validation). Cal/Val is essential to ensure the quality of satellite data. Earth observation satellites are satellites specially developed for Earth observation in orbit, similar to spy satellites, but intended for non-military applications such as environmental monitoring, meteorology, mapping of changes in soil vegetation, atmospheric composition and icefields etc. In EVDC, relevant data from all over the world are collected on a daily basis.

We also host the **ACTRIS** data center, which encompasses EBAS and two other external databases (CloudNet and EARLINET). It provides free and open access to all data derived from ACTRIS infrastructure network activities. The objective of the database is to help scientists gather and access atmospheric data from a number of databases distributed worldwide.

In Norway, the most well-known of our databases is **luftkvalitet.info**. In addition to being a web portal with information about air quality in Norwegian cities, it is also a database. It contains a large number of air quality measurements from several monitoring stations over many years. These data are also open to all, and are used by both scientists and citizens in a variety of contexts.

Setting up the "laughing gas" budg

"Laughing gas" sounds harmless enough. Known also as nitrous oxide, it is in fact the third most important greenhouse gas in the atmosphere, and no laughing matter.

Christine F. Solbakken
Head of Communications

Besides being an important greenhouse gas, nitrous oxide or N_2O is also one of the main ozone depleting substances in the atmosphere, since the Montréal protocol put a stop to the use of chlorofluorocarbons (CFCs). Thus, it is important to know as much as possible about all the processes producing N_2O.

Covering all angles

Rona L. Thompson is a senior scientist at NILU's dept. of atmosphere and climate, and co-leads the N_2O budget of the Global Carbon Project.

– I was asked to co-lead this new activity in December 2015, she says, – and we started working on it the following year. My part is related to atmospheric observations and modelling of N_2O.

Other scientists involved with the project work on agricultural emissions, natural emissions, wastewater emissions, and other aspects of the budget – namely, accounting for all N_2O emissions, sinks and changes.

Nitrous oxide (N_2O)

Nitrous oxide, also commonly known as laughing gas, is a gas with the formula N_2O. Nitrous oxide occurs in small amounts in the atmosphere, but plays an important role in stratospheric ozone loss, with emissions of N_2O being one of the largest sources of ozone depleting substances, and it is a greenhouse gas. It is estimated that 30% of the N_2O in the atmosphere is the result of human activity, chiefly agriculture.
(Source: Wikipedia)

Phto: Colourbox.

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Fertilisers are the main source

– The use of fertilisers in agriculture is the main source of nitrous oxide today, explains Thompson. – If we can decrease the use of nitrogen fertilisers, we would also see a decrease of N_2O in the atmosphere.

However, it is not so easy to reduce the use of nitrogen fertilisers, as they are necessary to grow enough food. In well-developed countries, farmers are now trying to use fertilisers more efficiently, managing to maintain or even increase crop yields with less. This is not the case in several emerging economies, such as in Asia, where the use of fertilisers is rising while the efficiency is going down.

Rona L. Thompson. Photo: Ingar Næss.

Making N_2O visible to the world

At the end of 2017, the project group has finished gathering data and estimates for all aspects of the N_2O budget.

– We are now starting to look at how it all fits together, Thompson says, – checking how the atmospheric increase in N_2O matches up with all the emissions and sinks. We are also planning to publish scientific articles as well as put all the results in the form of interactive graphics on the Global Carbon Project website, making it possible to view N_2O emissions globally and regionally.

What is the Global Carbon Project?

The Global Carbon Project (GCP) was established in 2001 to address the need for information about sources and uptakes of CO_2 in the ocean and land biosphere. The scientific goal of the project is to develop a complete picture of the global carbon cycle, as well as budgets of the three most important greenhouse gases, including both biophysical and human dimensions together with the interactions and feedbacks between them.

www.globalcarbonproject.org

COMTESSA: Understanding turbu

The ERC project COMTESSA (*Camera Observation and Modelling of 4D Tracer Dispersion in the Atmospher* is led by senior scientist Andreas Stohl from NILU's department of atmosphere and climate. COMTESSA elevate the theory and simulation of turbulent tracer dispersion in the atmosphere to a new level by perf completely novel high-resolution 4D measurements. In July 2017, the COMTESSA team were in the field, using UV and IR (infrared) cameras to track turbulence in the atmosphere.

Massimo Cassiani and Norbert Schmidbauer are adding a few more marks on the SO_2 gas flow meter. This was done for a sensitivity test – increasing the amount of SO_2 released and comparing this with the SO_2 fluxes measured with the cameras. Photo: Hamidreza Ardeshiri, NILU

Massimo Cassiani checks the equipment at the top of the mast. Photo: Hamidreza Ardeshiri, NILU

Soon-Young Park and Solvejg Dinger preparing the drone. Photo: Hamidreza Ardeshiri, NILU

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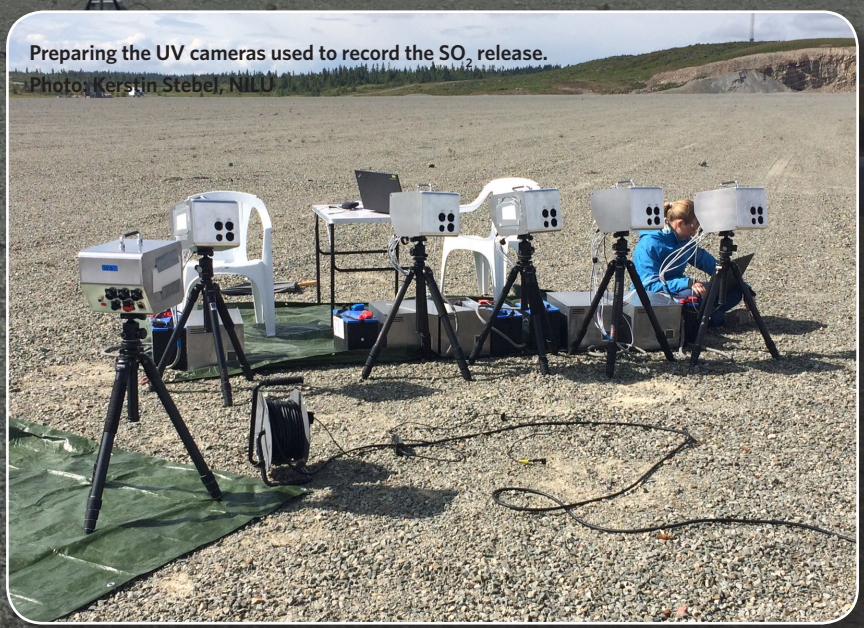
6 UV cameras were located nearby for a second sensitivity study, where the amount of SO_2 released was varied stepwise. On the tower we had 3 sets of meteorological instruments to measure the turbulence, and the SO_2 mixed with ambient air is released through the black pipe and nozzle visible at the top of the mast.
Photo: Kerstin Stebel, NILU



Preparing the UV cameras used to record the SO_2 release.
Photo: Kerstin Stebel, NILU

Photos on left page and background photo: Hamidreza Ardeshiri, NILU
Photos on this page: Kerstin Stebel, NILU

Data revolution in urban atmospheric research

During the last decade, the need for information and data has exploded, and this "data revolution" has not stopped short of science. In environmental research, data have become more and more important – to the point that scientists now even know what your fireplace looks like.

Susana Lopez-Aparicio
Senior Scientist

– Data collection is the key step in most environmental research fields. When developing high-resolution emissions of both air pollutants and greenhouse gases, the most crucial part is getting high quality data, explains Susana Lopez-Aparicio, senior scientist at the Urban Environment and Industry Department at NILU.

Wood burning data challenge

One of the biggest challenges is the characterisation of emissions from wood burning for residential heating. In Norway, wood burning is an important source of domestic heating, associated with a strong tradition of cosiness.

There are approx. 2.5 million wood burning stoves and over half of them are presumed to be in regular use. Wood burning in residential houses does not only provide a warm home, it is also one of the main contributors to harmful air pollutants (e.g. particulate matter-PM, polycyclic aromatic hydrocarbons-PAHs) and an important source of black carbon, a short-lived climate pollutant.

Lopez-Aparicio explains further: – When we want to characterise emissions of wood burning for residential heating, we need information about the wood consumed in the household, the type of stove the wood is burned in (e.g. fireplace, new or old ovens), the time period when wood burning occurs, and the type of dwelling; this indicates the height where emissions enter the atmosphere.

The machine learning model developed by NILU classifies different types of fireplaces found on the images the web crawler retrieves from finn.no, as shown in this example (illustration photo: Colorbox).

When working at city scale, scientists need information at both high spatial and temporal resolution, and those data are rarely available.

The wisdom of the crowd

In the iResponse project (http://iresponse-rri.com/), funded by the Research Council of Norway, the NILU team has developed and evaluated different methods based on crowdsourcing. The concept of crowdsourcing is based on collecting ideas, data and/or services from a large group of people by using information and communication technologies (ICTs). It has been defined as the new "paradigm of knowledge creation". One of the aims of iResponse is to address the challenges and opportunities associated with data collection methods to improve the understanding of emissions from wood burning for residential heating.

– In iResponse, we used two different approaches for data collection, explains Lopez-Aparicio, who coordinates the project. – The first method is based on citizen participation, and the second one on automatic data mining from online portals.

Citizen participation

Lopez-Aparicio and her team designed and tested two methods based on citizen participation. Both aimed to collect geo-localised data on wood consumption per citizen, the type of appliance they use for wood burning, and the time they burn wood.

The first method was based on an existing tool for collecting citizens' insights of their immediate environment based on geographical information systems (Maptionnaire; https://maptionnaire.com/). Case studies were carried out in Oslo, Akershus, Sarpsborg and


Photo: Stein Manø

Fredrikstad, resulting in around 1 000 geo-localised responses with information about the respondents' wood burning activities and their perception of the environment.

For the second method, a specific tool was designed to collect data about wood burning activities, and in return provides the participants with feedback regarding the economic cost and environmental impact associated with their activities.

– We identified important challenges in data collection based on citizen participation, such as volunteer engagement, data quality and sample representativeness, explains Lopez-Aparicio. – It requires a significant amount of resources to achieve a representative participation rate, and obtaining good quality data for use in environmental research is quite challenging.

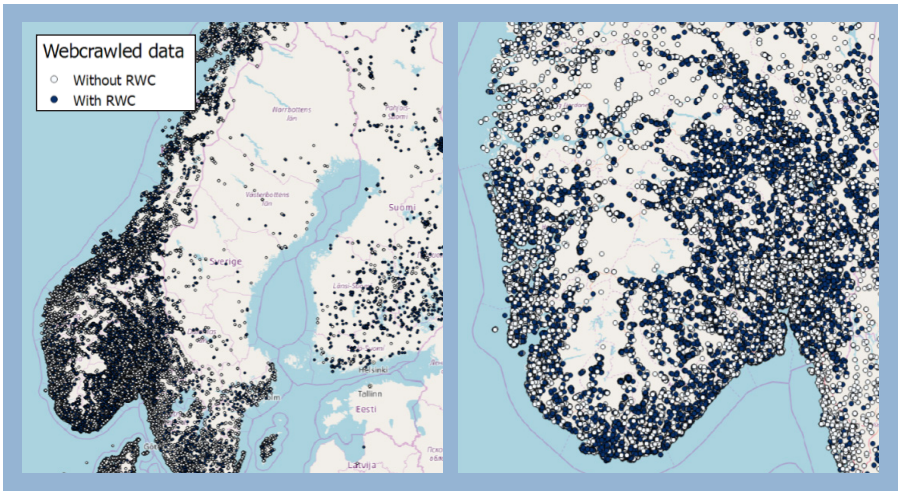
Automatic data mining

When developing an emission inventory for residential heating, some of the main questions are where the wood burning appliances are and in what type of dwelling. Knowing this, the team is able to identify wood burning potentials for specific areas. The iResponse project developed a method for automatic data mining from online portals where this information is available.

– We designed a so-called "web-crawling" method, says Lopez-Aparicio. – It retrieves the geographical position of the dwellings announced on Finn.no, the Norwegian classified advertisements website that covers the bulk majority of real estate transactions, and pictures from the dwellings' inside. The announcements give detailed descriptions of the properties, including the available heating system (e.g. heat pump, district heating, wood stove) and the type of dwelling (e.g. detached house, apartment, cabin).

Using machine learning to classify wood stoves

The NILU team developed a model for image recognition and classification based on machine learning. Based on the images collected from Finn.no, the model identifies the wood burning appliances and classifies them with a precision of 81%, 85% and 91% for open fireplaces, old stoves and new stoves, respectively.



Web crawler data from the Nordic countries. Figure: Susana Lopez-Aparicio, NILU

The data collected through web-crawling was a crucial piece of information in the development of a model to estimate high resolution emissions from wood burning. This is performed in the MetVed project, financed by the Norwegian Environment Agency and led by Lopez-Aparicio. Here, the analysis of data from different sources has showed the importance of data availability, and the need of more open data.

– Our work clearly demonstrates the potential of such methods to obtain data with high level of detail crucial in the development of emission inventories at urban scale, concludes Lopez-Aparicio.

Web crawling

A web crawler (also called web spider or web robot) is a program/automated script that browses the internet systematically and in an automated manner for information of interest

Data mining

Process of discovering interesting and useful patterns and relationships in large data sets to extract usable data.

The work described in this article has been carried out by this NILU team led by Lopez-Aparicio:

- Henrik Grythe: emission model development and data analysis
- Matthias Vogt: data analysis
- Islen Vallejo: development of the image recognition model based on machine learning

Polluted dust bunnies

Indoor environments, such as homes, work places and schools, contain a number of potential sources of both new and old environmental pollutants. To find out more about these contaminants, NILU scientists went searching for dust bunnies in Norwegian homes.

Sonja Grossberndt
Scientist

– We know that there are a large number of contaminants in the environment with the potential to harm both the ecosystem and human health. But we still know too little about their sources and which of these new contaminants may hurt us, explains senior scientist Pernilla Bohlin Nizzetto from NILU's Environmental Chemistry Department.

More pollutants inside than outside

We spend most of our time inside. This exposes us for a number of chemical compounds we neither see nor smell, but we nevertheless breathe. Several known chemical contaminants have been proven to be present in higher concentrations inside the house than outside. This is the result of emissions from products and materials we use indoors.

NILU scientists have been working hard to find out what compounds are present indoors, and how to collect suitable samples for analysis. It turns out that not only indoor air, but also household dust and dust bunnies, are full of environmental contaminants. This makes it quite easy to collect samples. Thus, NILU has – on behalf of the Norwegian Environment Agency – collected dust samples from several Norwegian households to analyse for a number of both known and also relatively new contaminants.

Hunting dust bunnies

– Most people are well aware of household dust and dust bunnies. They are easy to collect, and they are often found close to potential sources of the contaminants they contain, explains Nizzetto. Together with her colleagues at NILU, she has analysed both dust and indoor air samples and found many compounds with the potential to harm human health in high concentrations. The results are incorporated in the Environment Agency's annual monitoring report "Screening programme for new environmental compounds".

In addition to household dust and indoor air, scientists at NILU and NIVA (Norwegian Institute for Water Research) have also analysed samples from treatment plants and leachate from landfills, sediment, surface water and biota from the investigated treatment plants. The sample type with the highest number of positive findings was household dust and household dust in combination with indoor air.

How dangerous is it?

– I am not surprised about our findings, Nizzetto continues. – This is a natural consequence of the continuous development of new pollutants designed to be used in objects many of us have at home, such as cosmetics, cleaning products, clothes, furniture, and building materials.

So far, scientists do not know in what dose these contaminants are dangerous or harmful for human health. But if you are concerned about the products you buy, you can check the list of ingredients and choose those containing the least dangerous compounds.

– Not everybody can read the list of ingredients and understand what it says, says Nizzetto. – But you can get guidance through the swan label (the official Nordic ecolabel). In may also help to vacuum a bit more often than usual!

Mapping both occurrence and absence

So, if scientists currently cannot say anything about the health effects of the environmental contaminants we are exposed to in our homes – how can these results be of any benefit to us?

Martin Schlabach, senior scientist at NILU, provides an answer. He is responsible for the screening survey and explains that the results can be used to map both occurrence and absence of the different contaminants.

Many environmental contaminants appear indoors first, before they get out into the environment through for example ventilation, sewage or burning of waste. This is how the environmental contaminants are released into air, water and sediment, and are then transported to places far away from where they were originally "released".

Dust bunnies may contain harmful pollutants. Photo: NILU

– You could thus say that mapping serves as a sort of "early warning system", explains Schlabach. – By mapping the contaminants that occur in indoor environments, we can point to the pollutants that will sooner or later also occur outside. In addition, we might also be able to identify the possible sources.

Making an effort

Scientists all over the world are working hard to identify new environmental contaminants and their sources, and determine how dangerous they can potentially be for human health and the environment. One example of this effort is the international network "NORMAN" (http://www.norman-network.net/), where reference laboratories, research institutes and related organisations work together on the surveillance of new environmental contaminants. The network consists of 50 plus members from more than 19 countries, collaborating in different working groups. NILU's Pernilla Bohlin Nizzetto is coordinating NORMAN's working group on the improvement of methods to identify and monitor new environmental contaminants indoors, to improve their risk assessment. Improved risk assessment will provide for better opportunities to establish stronger regulations – or even a ban – on the use of certain environmental contaminants.

– It is still a way to go, but we are headed in the right direction. The more results we obtain through our studies and analyses, the easier it will be to reach this goal, concludes Nizzetto.

Smart nanoparticles combating cancer

Nanomedicine creates unique opportunities for therapeutic treatment, with multifunctional nanoparticles having a big potential for cancer treatment. NILU is now working on making smart nanoparticles safe to use in both diagnostics and treatment of lung cancer.

Elise Rundén Pran
Senior Scientist

NILU is partner in the research project GEMNS – "graphene-encapsulated magnetic nanoparticles". The aim of this project is to develop safe, multifunctional nanoparticles that can be used for both imaging methods and treatment of lung cancer.

Jigsaw puzzle on nanoscale

In this project, the surface of nanoparticles are treated in a way that enables them to recognise and connect to cancer cells only, and not to normal lung cells. When the GEMNS-particles connect to the receptors on the surface of cancer cells, they release an enzyme that kills those cancer cells, not the healthy lung cells. After further development, this method is intended to be used for targeted radiotherapy.

Safe-by-design

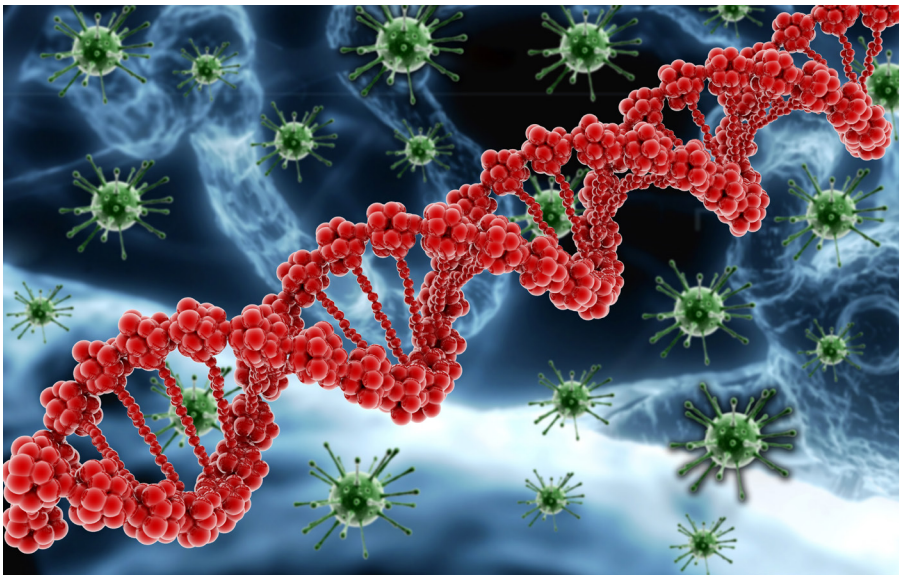
Whenever scientists develop new nanomaterials, especially for use in nanomedicine, it is essential that the nanoparticles are safe in their use. Therefore, GEMNS-nanoparticles are tested to find out how toxic they are (so called "toxicity testing"). One part of the testing process is to assess how safe these particles are for further medical use. This testing is carried out in accordance with global regulatory requirements.

The project uses the "safe-by-design" principal, where toxicity testing is carried out in parallel with the further development of the GEMNS-nanoparticles. Scientists are developing four different generations of GEMNS-nanoparticles, each of them with a new element on their surface. Then they test each generation for toxicity and investigate which version is least toxic. The least toxic version is then used for further development of the next particle generations after the same pattern. This kind of proceeding for nanosafety is both cost and time effective.

Testing for toxicity and effectivity

Until now, NILU-scientists have tested the toxicity of different metal cores, of different sized chain-shaped molecules (polymers) connected to the particles' surface and different lengths of links that will connect to these chains. The scientists have applied different tests for acute toxicity for lung cells (cytotoxicity), and all tests are standardised and validated for testing of nanomaterials.

GEMNS-nanoparticles are also being tested to reduce their probability damaging DNA or changing gene expression (epigenetic modification of global DNA methylation). The tests are carried out in human lung epithelial cells. In addition to the lab work, NILU's partners carry out effect studies and make use of modelling to study the potential context between structure of GEMNS-nanoparticles and effect (quantitative structure- and activity models (QSAR)). The project has so far been successful and the fourth and last generation of GEMNS-nanoparticles will soon be finished synthesizing and are ready to be tested for toxicity and effectivity.



DNA and cancer cells. Photo: Shutterstock

About the GEMNS-project

GEMNS is a 3-years project, financed by EuroNanoMedII, an ERA-NET under EU's 7th Framework Programme. It has a total budget of 1,6 million Euros. The objective of the EuroNanoMed programme is to transfer nanomedical research (use of nanotechnology for medical purpose and health treatment) from lab to clinic. GEMNS has four Polish partners, one from Romania and two from Norway – University in Bergen and NILU's Health Effect Laboratory (HEL). In the GEMNS-project, NILU's HEL shall use their large expertise from many international projects within nanotoxicology to carry out toxicity-testing of nanomaterials and nanosafety.

Thousands played soccer for science

What engaged 12624 students from 286 schools in 144 Norwegian municipalities in 2017? That would be the research campaign "Check your artificial turf soccer field"!

Christine F. Solbakken
Head of Communications

– We knew that around 3000 tonnes of crumb rubber disappear from Norwegian artificial turf soccer fields every year, explains senior scientist Dorte Herzke from NILU's Environmental Chemistry department. – But we wanted to find out more about what happens when the crumb rubber disappears, because they can contain environmental pollutants and be eaten by animals, which is not good for either the animals or the environment.

Unique research project involving kids

To gain more knowledge Herzke, in cooperation with scientists from Akvaplan-niva AS, Sintef Ocean, the Norwegian Institute of Marine Research, the Norwegian Research Council and the Environmental Education Network (The Centre for Science Education at University of Bergen) came up with the idea of involving children and teenagers in a research campaign. After all, they are the ones using the artificial turf soccer fields!

– We wanted to instill knowledge about microplastics and raise awareness about the use of crumb rubber on artificial turf soccer fields all over Norway, Herzke continues. – We would also like to know more about where these soccer fields are, what kind of crumb rubber is used the most, and what affects the wastage. What we discovered during this project is unique – no one else has done anything like this anywhere in the world – and it is immensely valuable for further research. And as a bonus, we got the students out of the classrooms.

To find out more, schools across Norway were invited to contribute data from their local soccer field via the web site "Check your artificial turf soccer field". Students and teachers examined the crumb rubber on their local soccer fields and played football matches. After the match, they checked the amount of crumb rubber attached to their clothes and shoes, and reported it to the database in terms of milliliters of crumb rubber per game, later converted to milliliter per player. They also included information about weather, number of players, duration of the match, and location and size of the soccer field.

Students from Elvebakken High School participated in the campaign during the fall of 2017. Photo: Christine F. Solbakken, NILU.

Gathering crumb rubber at the artificial turf soccer field at Voldsløkka in Oslo. Photo: Christine F. Solbakken, NILU.

Top engagement, important findings

In total, 12624 students and 403 teachers from 286 schools in 144 municipalities played 594 soccer matches lasting an average of 29 minutes. They have checked 344 soccer fields, and each player has brought approximately 1.9 ml. crumb rubber away from the field after a match.

How does crumb rubber disappear?

Each regular artificial turf soccer field for 11 players is covered with between 100-200 tonnes of crumb rubber. Danish figures show that between 1.5 and 2.5 tonnes of rubber disappear from each of them every year. In Norway we have approx. 1600 artificial turf soccer fields, of which there are 1058 "11-fields". The rest are smaller soccer fields and enclosed mini fields. According to the figures from Denmark, that means that between 1600 and 2650 tonnes of crumb rubber will disappear from the "11-fields" each year. This is a lot of rubber. Thus, the Norwegian scientists wanted to find out whether these numbers were correct, how the crumb rubber disappears, and whether it is possible to do anything about it.

See results from "Check your artificial turf soccer field" here (in Norwegian only).

– The students and teachers have contributed to an important finding, we now know that in 2017, more than 80% of the crumb rubber on Norwegian artificial turf soccer fields were made of SBR, that is, used car tires, Herzke says. – We also know that the weather plays an important role when it comes to the amount of crumb rubber transported off the field. When it is wet, more rubber attaches to shoes and clothes and is carried away.

The scientists have used the data from the campaign to calculate how much rubber is lost as particles from Norwegian football fields every year. The Football Association of Norway annually arranges 355,000 matches, amounting to about 44 ml per game (2x11 players), in total 14740 liters. 14 740 liters of crumb rubber weigh approx. 6.5 tonnes. The scientists have further assumed that there are about ten times as many training matches played as official matches, thus concluding that players transport ca. 65 tonnes of crumb rubber away from Norwegian soccer fields each year.

– The crumb rubber does not only disappear after soccer matches, says Herzke. – A lot of crumb rubber disappears from the artificial turf soccer fields through direct drainage through the drains on the fields through the action of wind and weather, or when snow is cleared. However, regardless of how it is transported away from the fields, a lot of the crumb rubber may finally end up in the ocean. This is due to insufficient wastewater treatment over large parts of the country. So, we need to look further into this in the future.

What is crumb rubber made of?

Various types of crumb rubber is used on Norwegian artificial turf soccer fields. The most commonly used is SBR from recycled car tires. In addition comes TPE, which is artificially manufactured and comes in several colors and shapes, and EPDM. EPDM is similar to SBR in shape, but can be delivered in different colors. Also occurring is crumb made of granulated cork.

"Check your artificial turf soccer field" was a collaboration between NILU, Akvaplan-niva AS, Sintef Ocean, the Norwegian Institute of Marine Research, the Norwegian Research Council and the Environmental Education Network. The Fram Centre sponsored the campaign.

The results from "Check your artificial turf soccer field" will be directly used in the ongoing research project *Microplastics from artificial sports pitches: composition, degradation and biological interactions (MARS)*, financed with funding from the Fram Centre.

When research leads to innovation

For several years, NILU has had its main focus on developing new projects and establishing innovative services. Involvement across departments has proven to be a good recipe for solid opportunities.

Christine F. Solbakken
Head of Communications

NILU's innovation strategy states that "Innovation shall contribute to making use of NILU's research in new areas and ways in society". This is the basis for the Innovation Department at NILU which, as of today, consists of four employees.

Internal innovation support

Rune Ødegård, head of development of NILU's Software and Hardware Development Department (SHADE), is by now used to thinking outside the box and looking for new solutions and opportunities that may be further developed in a commercial setting. He and his employees are happy to work with the Innovation Department.

– It is important to be open for opportunities, he says, – and with the help of the Innovation Department, my employees have started to discover NILU's innovation support. Now, new ideas about innovation projects keep popping up, not least because both follow-up and facilitation have become far more professional during the last years.

Several ways to go

Internal support for innovation is an active approach from NILU's side. The institute has had its own Director of Innovation since 2008, and since then people have been working across departments to build up both software and hardware services. The Innovation Department is focusing on discovering and developing innovative services with potential to develop into something bigger in the future.

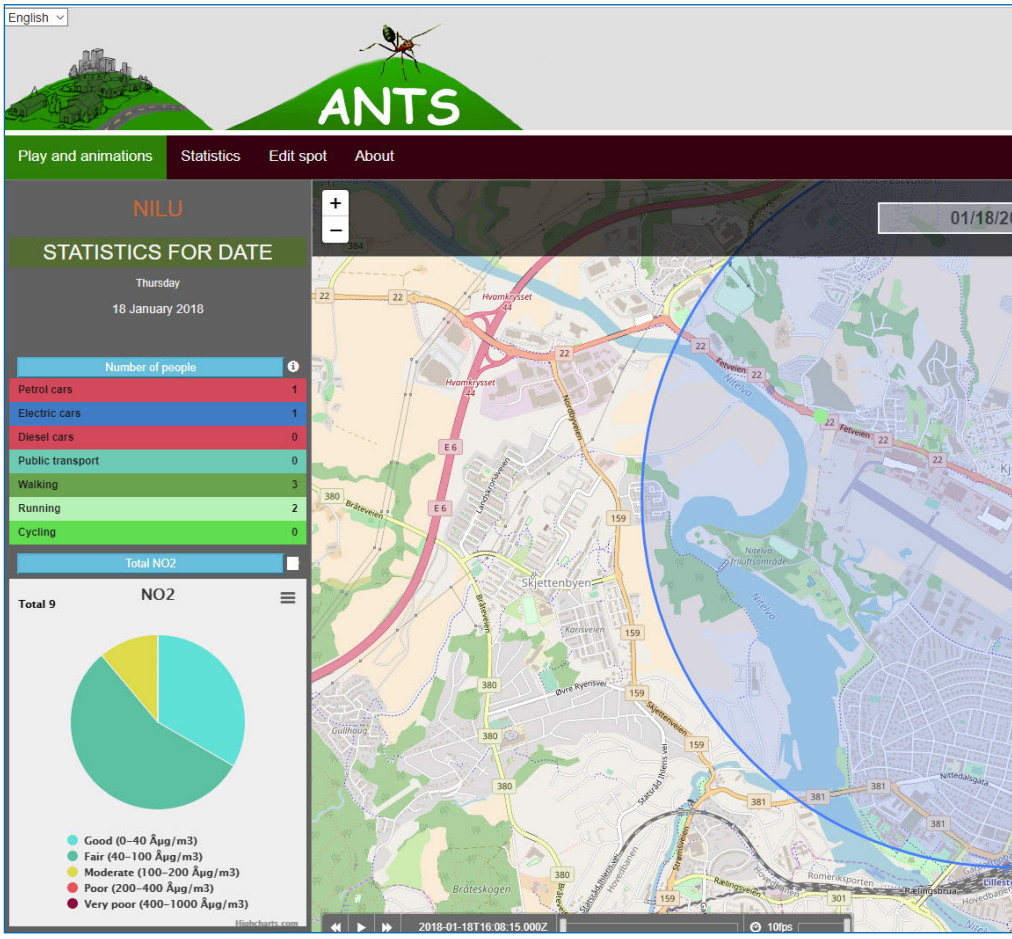
– Innovation for us at NILU is about finding the best strategies for implementation and broad application of new solutions, both in terms of products and services. This could be open source agreements, licensing, establishing a new company, or licensing solutions for actors from the public or private sector, says Director of Innovation, Pål Midtlien Danielsen.

Follow-up to a political initiative

There is solid political support for green, digital solutions. The Norwegian Research Council (NFR) puts much emphasis on innovation and user driven projects, and especially NFR's BIA programme (User-driven Research based Innovation) will become more important for NILU in the future.

NILU's innovation projects and recently started companies

- INNOSENSE: In cooperation with NILU, InnoSense AS has developed a groundbreaking microsensor platform that is both precise and cost effective in measuring relevant gasses in the air.
- ECLECTIC is a new company with the purpose of offering air quality services to the car industry:
  - *SMART air inlet*
  - *Green zones*
  - *We CARe app*
- Leopard – development of a portable particle/dust sensor to be used in industry.
- ANTS – development of a gamification based mobile app that motivates people to choose more green transport alternatives.
- • "Modeling as a Service" – is under development. NILU wants to offer services to municipalities to develop dispersion models and different measures through a user-friendly web service.
- Bedrock – development of a simple sensor to measure the distance from the earth's surface to bedrock.



Screenshot from the mobile app ANTS.

– BIA focusses on the development of solutions for cooperation within the private sector, says Danielsen. – We have to demonstrate our ability to involve users. This is very exciting and we see many opportunities for NILU. Another interesting programme is ICT in Horizon 2020 (ICT LEIT), with several current announcements in 2018.

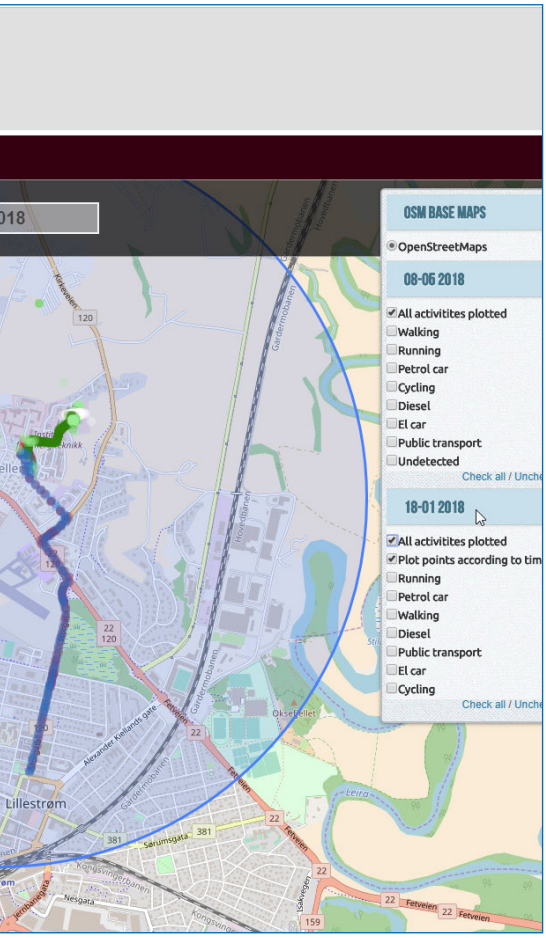
– There is room for much innovation in these programmes, Ødegård says. – When an idea is developed into its own company, SHADE is still important for them since we continue to take care of the company's interests.

Not all research takes decades

Whenever NILU is establishing new companies, either subsidiaries or independent companies, there is an opportunity for further cooperation and new projects for NILU.

– Innovative thinking is mainly about learning to think differently, says Ødegård.

– We see new opportunities, we look for new partners. We have also become better at demonstrating that science may actually be business friendly. Not all research takes decades to complete!



Goal: Solutions that give environmental benefits


Photo: Ingunn Trones, NILU.

When societies develop, the goals they aim for change. In recent years, sustainable solutions with environmental benefits have become increasingly important, both politically and scientifically. Such solutions are central to further development within industry and business as well.

– Commissions from industry amount to approx. 15% of NILU's revenue. Consequently, we see that industry and the private business sector are increasingly important for sustainable societal development, says Leonor Tarrasón, research director for environmental solutions at NILU.

The research director position was established in 2017, to strengthen and further develop the institute's contribution towards the green shift. Tarrasón is clear that now is the time to take action.

– In Norway, we have an advantage due to not having only a few market giants. Instead, we have many small players who can gather in clusters to accommodate innovation and growth. The challenge is to grow healthily while developing further, she says.

The solution for healthy growth, according to Tarrasón, lies in science. It is about exploiting different types of knowledge. Facilitating cooperation between scientists, politicians, industry and business actors can mean a lot for further development of innovative clusters in Norway.

– Therefore, it is important that we, as scientists, get better at expanding our networks, she says. – We need to work more interdisciplinary and be more socially responsible. Neither science nor innovation can exist in a vacuum, that is not gainful, so scientists must join the playing field earlier.

Tarrasón wishes to challenge NILU not only to identify the impact of measures, but also to develop solutions and methods for the purpose of avoiding negative effects. The idea is that if one works from the start with identifying and eliminating possible negative effects, one will end up with solutions more well thought through, which are also better for the environment.

– We are in the lucky position that NILU is an interdisciplinary institute with broad and solid expertise in a number of different fields, and we must make use of that, she says. – We need to identify complementarities and synergies, think new and explore what opportunities we have regardless of traditional roles and patterns. We have the laboratories, we have the technology, we just need to gather the great minds and set them to develop new ideas.

Carbon footprinting and life cycle assessment

You are probably familiar with the term "Carbon footprint". But do you also know how it is calculated and what it can be used for?

Sonja Grossberndt, Scientist, and Evert Alwin Bouman, Scientist

As many might know, a "Carbon footprint" stands for the total amount of greenhouse gases (GHGs) or carbon dioxide released into the atmosphere as a result of different activities. Carbon footprints include both *direct* and *indirect* emissions. *Direct* emissions are those emissions occurring during a specific activity, e.g. emissions from petrol combustion while driving a car. *Indirect* emissions are associated with the entire value chain that supports the activity in question. They occur e.g. during production of a car and its components.

Quantifying carbon and other environmental footprints

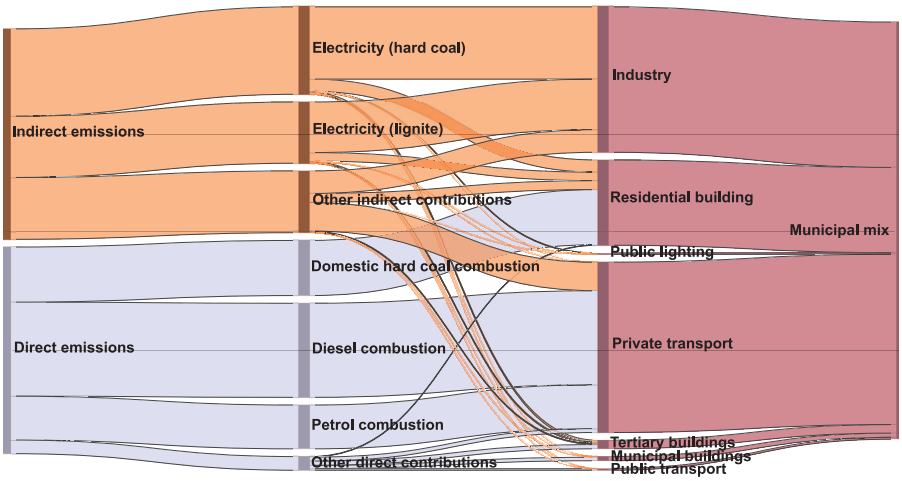
– Environmental footprints of singular activities can be calculated using Life Cycle Assessment (LCA), explains Evert Bouman, scientist at NILU's Department for Environmental Impacts and Sustainability. LCA is a tool for quantifying and assessing a range of potential environmental impacts of product use or services. It can help identify unforeseen consequences – so-called "environmental problem shifting". Problem shifting can occur when a proposed solution to reduce (direct) emissions from an activity results in increased emissions elsewhere. For example, capture of CO_2 at a power plant requires energy and reduces its net efficiency. Thus more coal or natural gas needs to be combusted, increasing resource requirements and emissions upstream. Not only can LCA quantify product carbon footprints, the tool also allows for the calculation of other environmental impacts, such as impacts of emissions on health and ecosystems. The quantification of these environmental footprints and identification of potential problem shifting thus provides a basis for choosing the most environmentally sustainable solution.

Energy balance and carbon footprint in Poland

In 2017, NILU's Rebecca Thorne, Evert Bouman and Cristina Guerreiro were involved in calculating the energy balance and carbon footprints of 17 different Polish municipalities in a project funded through the EEA-Norway Grants and led by Częstochowa Polytechnic University. All municipalities were asked to submit their energy usage data to NILU classified by sector (e.g. transport, heating and lighting) and energy carrier (e.g. electricity, petrol and coal). The NILU-team used these data to construct a life cycle model and calculated footprints for each municipality. The NILU analysis also broke down the footprint by sector and energy carrier contributions.

– Example results are shown for one municipality in the following figure, Bouman continues. – Industry, residential buildings, and private transport sectors are the most significant sources of emissions. However, whereas most emissions from private transport and building activities are direct (from combustion processes), emissions from industry are indirect (from electricity usage). The figure also acts as a guide as to where policies may have the greatest effect when targeting emission reductions. For example, for this municipality, new policies related to reducing emissions in public transport will have a smaller effect on total municipal emissions than policies related to industry or private transport.

– Our experiences in Poland have shown that there is no single policy to reduce municipal GHG emissions as the sectors contributing most to the carbon footprint differed considerably between municipalities, concludes Bouman. Rather, municipal climate and energy planning benefits from tailor-made solutions. The example of the Polish municipalities shows that LCA is a valuable tool to support environmental decision-making and it will be a core method for IMPACT's sustainability assessment services in the future.



Relative contribution of sectors and energy carriers to the carbon footprint of one of the participating Polish municipalities

Environmental forensics – chasing environmental offenders

Oil spills, tanker accidents, chemical disasters – suddenly materials are released into the environment, potentially harming both humans and nature. Is it possible for scientists to trace the environmental offenders?

Sonja Grossberndt, Scientist, and Stephen Michael Mudge, Senior Scientist

– The answer is yes, says Stephen Michael Mudge, senior scientist at the Environmental Impacts and Sustainability Department at NILU.

Environmental CSI

This field of science is called environmental forensics, and it sounds a lot like hands-on work at a crime scene.
– It is actually not that different as every contact leaves a trace, Mudge explains.
– Environmental forensics describes the scientific study of contaminants in the environment. With the aid of modern technology, we can identify their source(s), the hazard posed, the time between release and measurement and the magnitude of any biological effects.

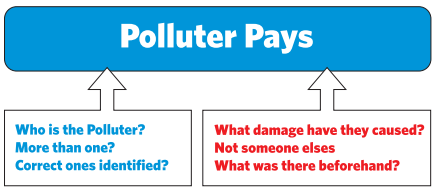
Stephen Michael Mudge. Photo: Finn Bjørklid.

Knowing all this also helps when deciding on the best remediation strategy. Such approaches may be used by industries, regulators and lawyers, both during and after contamination events.

Source – pathway – receptor

Mudge has a long expertise from many environmental forensic cases.

– Usually, we are looking for one or more potential sources of contaminants to the environment, he explains. – The contaminants often use multiple pathways by which they may be transported from the source to a receptor. This may be in the air, water, sediments or soil, or plants, animals and humans. If the receptor is a living organism, it is also necessary to measure the potential effects the source(s) may have on the living organism.



The "Polluter Pays" Principle

The "polluter pays" principle has been an important aspect of recent environmental legislation, although the simplicity of the phrase hides a complex series of questions: Who is/are the polluters? How much did each contribute to the system? What "damage" did they cause? Can you differentiate between historical and natural sources and recently spilled compounds? What should the polluters pay for? How do you "compensate" for the damage? Environmental forensic investigations can answer these questions.

Environmental forensics at NILU

Environmental forensics is a new field at NILU. NILU already has significant analytical capabilities, and the development of the environmental forensic approach will make use of these sensitive instruments to provide additional insight into the state of the environment.
This will also be extended into the reconstruction of environmental histories to provide evidence of change in the environment. These changes may be due to natural processes, climate induced alterations or through technological events. This includes spills, planned or unplanned. For instance, certain trees are good at recording some of the airborne contaminant load within their rings. Analysis of these rings can provide a relatively high-resolution record of the concentration of these contaminants reached in the past.
– Environmental forensics is a very exciting field that offers for a range of research opportunities. I'm quite excited to implement this field further at NILU, says Mudge.

Did you know it is possible to:

- Determine the potential discharge date of some compounds?
- Separate recent discharges from old discharges of the same material?
- Determine the background and baseline condition prior to a release?
- Calculate the source apportionment within complex mixtures?
- Trace the pathway of contaminants through the environment?

Looking into volcanic emission

Volcanic gas emissions can affect the climate, environment and society, not only in the case of violent eruptions but also under quiescent degassing conditions.

Jonas Gliß defended his PhD, carried out at NILU's department of Atmosphere and Climate, at the University of Oslo's Department of Physics on November 10 2017. The title of his thesis is "Passive UV remote sensing of volcanic sulphur and halogen emissions".

The PhD thesis provides new insights into the impacts of volcanic halogen emissions and furthermore, provides new analysis methods and software that will help reducing the uncertainties related to the estimation of volcanic sulphur emissions.

Jonas Gliß defended his PhD in November 2017.

Impacting the climate

In the thesis, Gliß focusses on measurements of volcanic gas emissions and their impact on the environment and society, using optical remote sensing techniques. Particularly, he examines the emissions of halogens (bromine and chlorine) and sulphur species, which can have tremendous impact on both local and global scales.

– Sulphur dioxide (SO_2) can be harmful for humans and animals in high concentrations and can have severe impact on both aquatic and terrestrial environment in the form of acid rain, Gliß explains. – In addition, being a precursor of sulphur aerosols, SO_2 can directly impact the climate, especially in the case of violent explosive eruptions, where the gases can reach the stratosphere. Here, the aerosols can remain on timescales of months to years, and can counteract global warming by acting as a "mirror" that is back-reflecting incoming solar radiation. A famous example is the eruption of the Philippine volcano Mt. Pinatubo in 1991, which caused a decrease in the global average tropospheric temperature of 0.5–1.0°C in the aftermath of the eruption.

– The emissions of halogen species can impact the oxidation state and reactivity of the atmosphere, says Gliß. – Within a volcanic plume, they are converted into highly reactive halogen radicals which can effectively impact abundances of climate relevant gases such as ozone (O_3) and methane (CH_4).

In his PhD work, Gliß is the first to investigate the combined chemical evolution of reactive chlorine and bromine in the young emission plume of Mt. Etna in Italy, using the spectroscopic technique of Differential Optical Absorption Spectroscopy (DOAS). The measurements lead to better understanding of the halogen chemistry of chlorine in volcanic plumes, particularly the associated impacts on the climate (e.g. depletion of ozone and methane).

Better SO_2 estimates

The second part of the thesis focuses on the technique of UV SO_2 cameras. The imaging devices can be used to measure the total volcanic emission-budget of the toxic pollutant sulphur dioxide (SO_2) using ultraviolet (UV) sunlight as a light source.

Gliß developed the open source software Pyplis as part of his PhD. The software comprises a comprehensive collection of algorithms and routines relevant for the analysis of the image data, in order to retrieve SO_2-emission-rates. Pyplis aims to unify different analysis methods, offering more transparency, more efficient analyses and the possibility to perform inter-comparison studies.

The retrieval of volcanic SO_2 emission-rates requires knowledge of the gas velocities in the emission plume. These can be measured from the UV images directly using optical flow algorithms. Optical flow algorithms track contrast features in consecutive images and allow for velocity retrievals at the pixel-level. But a common issue of such algorithms is that they cannot detect motion in homogeneous image areas, and this can lead to significant underestimations of the SO_2 emission-rates.

In his thesis, Gliß proposes a correction based on a local statistical analysis of a velocity field retrieved using an optical flow algorithm. Using two datasets from Mt. Etna, Italy and Guallatiri, Chile, he shows that the proposed correction for erroneous motion estimates works well and can significantly improve the robustness and reliability of the analysis. In addition, the study provides the first measurements of SO_2 emission-rates from the volcano Guallatiri.

Key figures

Extract from the annual statement: All figures in MNOK

Income statement	2017	2016
Project revenue	149,9	158,0
Basic grant*	29,4	28,4
National tasks and assignments	16,3	16,3
STIM-EU	4,3	3,5
Other operating income	0,1	0,8
Operating revenue	**200,0**	**207,0**
Wages and social expenses	-136,6	-138,1
Direct project expenses	-24,6	-27,8
Other expenses	-35,7	-35,9
Operating profit	**3,1**	**5,3**
Net financial items	0,3	-1,0
Tax	-2,0	-2,3
Profit for the year	**1,4**	**2,0**

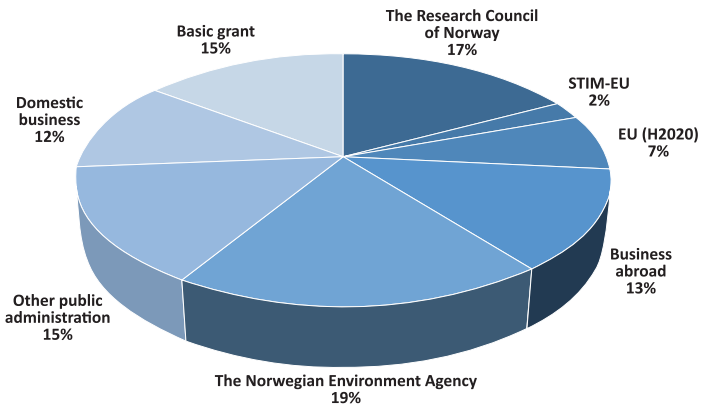
Balance sheet	31.12.17	31.12.16
Fixed assets	98,7	100,0
Current assets	100,5	96,9
Total assets	**199,2**	**196,9**
Total equity	123,8	122,4
Short-term liabilities	75,4	74,5
Total equity and liabilities	**199,2**	**196,9**

Number of man-years	2017	2016
Total	162	163
– whereof research man-year	104	104
– whereof man-years of other personnel	58	59
Turnover per research man-year (MNOK)	**1 923**	**1 990**

Number of employees	31.12.17	31.12.16
Total from over 20 different nations	171	176
– whereof women	86	92
– whereof men	85	84
Number of employees holding a doctorate	**69**	**68**

NILU's publications	2017	2016
Peer-review articles	130	130
Scientific reports	45	35
EMEP/CCC reports	4	4
Lectures	170	136
Posters	26	41
NILU's scientists also contributed to the publication of:		
External reports	41	20
Chapters/articles in books/reports	20	33

PROJECT PORTOFOLIO – PERCENTAGE 2017



**strategic institute initiatives included*

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