How to use the power of AI to reduce the impact of climate change on Switzerland

Recommendations for the Swiss society and economy to become more resilient against the impact from a radically changing climate

Make key technologies broadly available and overcome challenges through key methodologies in climate- and AI-related fields.

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8.3 Case-Study #2: Greenhouse Gas Emission Monitoring

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8.3.1 Motivation and Methodologies of Greenhouse Gas Emission Monitoring

The signatory parties of the Paris Agreement on Climate Change are required to report their greenhouse gas (GHG) emissions as part of the enhanced transparency framework. The collective progress towards achieving the purpose of the agreement is then assessed every five years in global stocktakes that evaluate the world's progress towards net-zero emissions and, if necessary, prompts the implementation of more ambitious actions (UNFCCC, 2015). Currently, countries mainly report their emissions through emission inventories that are compiled from socioeconomic and environmental statistics following the IPCC Guidelines for National Greenhouse Gas Inventories [IPCC 2019]. However, the compilation and processing of the required data for producing GHG inventories is resource-intensive, time-consuming, and associated with high uncertainty, and thus insufficient for assessing the impact of policies in near real-time (Pinty et al., 2018). To better support the mitigation actions of the parties, measurement-based monitoring systems are in development that provide global information on GHG emissions in a consistent, reliable, and timely manner. Measurement-based monitoring systems determine emissions of countries, regions, and hot spots (i.e., cities, power plants and industrial facilities) using coupled data assimilation systems that combine in situ and satellite measurements of atmospheric GHGs with atmospheric transport simulations (see Figure 8.2) (Janssens-Maenhout et al., 2020). They will improve current inventories and provide data where currently no inventories are available.

AI plays an important role for such monitoring systems making it possible to process a large amount of data accurately in a timely manner. AI-driven algorithms will be used for retrieving GHGs from remote sensing measurements, for detecting and quantifying emission hot spots in the remote sensing images, for advancing atmospheric modelling systems (e.g., very fast radiative transfer and chemistry schemes), for mapping model fields to observations, and for downscaling global products for stakeholder uptake such as product carbon footprints (see Case Study #1, Section 8.2).

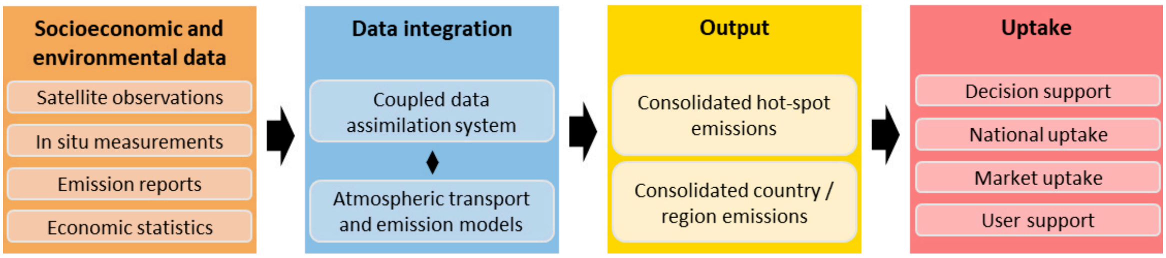

Figure 8.2: The dataflow of a GHG monitoring system based on the Copernicus CO_2 Monitoring System (Janssens-Maenhout et al., 2020)

8.3.2 Applications and Beneficiaries of Greenhouse Gas Emission Monitoring

GHG monitoring systems will benefit the parties of the Paris Agreement by providing global maps of GHG emissions (carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O)) at high spatial resolution that will provide support in the validation of emission inventories. Consistent, global GHG emission datasets are an important input for modelling consumption based GHG emissions that adjust national emissions for trade.

CO_2 is emitted primarily by fossil-fuel combustion from electricity and heat production, industry and transportation. CO_2 emission monitoring of hot spots will support cities and industry in monitoring their reduction measures. N_2O is mainly emitted by the agriculture sector, primarily associated with fertilization, animal excreta in grazing livestock systems, and crop residues (Velthof and Rietra, 2018; Hergoualc'h et al., 2019). Countries with complex agricultural systems, like Switzerland, with diversified crop rotations and grassland categories, can benefit from a reliable and efficient N_2O monitoring. CH_4 is another major GHG emitted by the oil and gas sector, livestock farming, landfills and waste, and coal mining. CH_4 emission reductions constitute an attractive target for climate change mitigation because it can be captured and used, for example, for energy production. CH_4 emissions, for example, from leakages have high uncertainty and measurement-based emission monitoring can guide cost and time effective mitigation strategies.

8.3.3 Roadmap and Available Services of Greenhouse Gas Emission Monitoring

The development of an emission monitoring system requires the development of the in situ and satellite measurement infrastructure and the data integration system processing the observations to obtain consolidated country, region, and hot spot emissions. Finally, it will be necessary to develop products and services to provide the required support to the different stakeholders. The first two components are currently in active development and planned to be available for the second global stocktake in 2028.

Environmental measurements: GHG emission monitoring requires observations with (1) high accuracy to identify the signals from individual sources, (2) imaging capabilities to resolve emission plumes, and (3) global coverage to support the Paris Agreement (Janssens-Maenhout et al., 2020).

CH_4 observations from space are available from area mappers that provide ***global coverage*** with spatial resolution of a few kilometers that can detect methane anomalies (e.g., GOSAT and TROPOMI) and imagers that are able to resolve strong ***point sources*** at about 100 m resolution (e.g., Landsat, Sentinel-2, GHGSat and PRISMA) (Jacob et al., 2022). In addition, airborne imagers have been used to determine CH_4 emissions from weaker sources at 1–10 m resolution.

The feasibility for quantifying anthropogenic CO_2 emissions with satellite measurements has been demonstrated with the OCO-2 and OCO-3 satellite at 2 km resolution (Nassar et al., 2017; 2022; Weir et al., 2021). However, there are currently no CO_2 satellites that fulfill the requirements for a global monitoring system. To fill this gap, Europe is building the Copernicus CO_2 Monitoring Mission (CO2M), which will be a constellation of two or more satellites that provide CO_2 and CH_4 satellite images at 2 km resolution with weekly global coverage (see Figure 8.3). The first CO2M satellites will be launched in 2026. Likewise, Japan is developing the GOSAT-GW mission that is planned for launch in 2024. Point source imagers with high spatial resolution are also available or in preparation (GHGSat, TANGO and CO2Image). The CO_2 satellites are supplemented by tropospheric monitoring instruments measuring co-emitted carbon monoxide (CO) and nitrogen dioxide (NO_2) (Sentinel-5P, GEMS, TEMPO, Sentinel-4 and Sentinel-5).

N_2O monitoring missions for area sources have been suggested for ESA's Earth Explorer 11 (i.e., MIN2OS (Ricaud et al., 2021)). Since the mission was not successful, there is currently no imminent mission that can monitor N_2O emissions on the regional scale.

In addition to satellite observations, ground-based and airborne measurement are critical for the validation of the global system. International networks such as ICOS[109], ACTRIS[110] and AGAGE[111] are critical to produce standardized, high-precision and long-term measurements. Airborne measurement campaigns will be possible, for example, with the Swiss Airborne Research Facility for the Earth System (ARES[112]) that will be able to monitor CH_4 leakages at facility level.

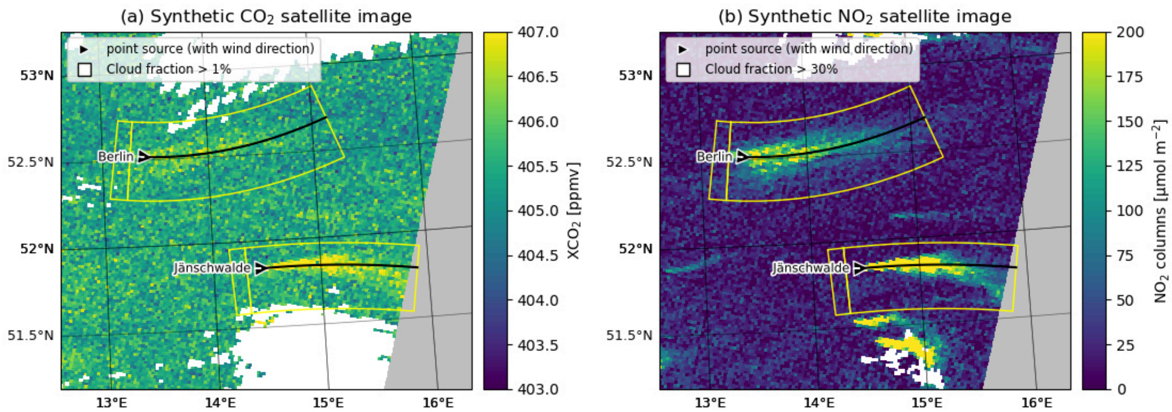

Figure 8.3: Model simulation showing expected CO_2 and NO_2 satellite images (2km resolution) of the upcoming CO2M satellite constellation. The images show the emission plumes of the city of Berlin and a power plant near Jänschwalde, from which CO_2 emissions can be determined using machine-learning models (Kuhlmann et al., 2019).

GHG monitoring systems: Many operational monitoring systems are currently being developed, including NASA's Carbon Monitoring System (CMS), the European Monitoring and Verification Support (MVS) capacity, and many national activities around the globe. The global efforts are coordinated by the WMO Global Greenhouse Gas Watch (G3W) program established in 2023. Methane activities are coordinated by the UNEP's International Methane Emissions Observatory (IMEO). The European GHG monitoring system will be implemented as part of the Copernicus Atmospheric Monitoring Service (CAMS) in ECMWF's Integrated Forecasting System (IFS). The prototype system is being developed in the Horizon 2020 CoCO2 project[113] and other Horizon Europe projects (e.g., CORSO[114]). In the IFS model, ***machine-learning models*** are developed to map model fields to satellite observations and to develop faster algorithms, for example, for atmospheric chemistry and radiative transfer. For hot spots, the large number of images provided by satellites requires fast algorithms for which machine-learning models have been identified as the most promising candidates. The main challenge is the lack of training data, because information on true emissions at satellite overpass is generally not available or only known with large uncertainties. Machine-learning models were therefore trained with synthetic satellite observations generated from highly realistic atmospheric transport simulations, which requires access to high performance computers (Jongaramrungruang et al., 2022; Joyce et al., 2023; Dumont Le Brazidec et al., 2023).

Uptake: Output from the GHG monitoring system will be taken up by the scientific community, companies, and NGOs to develop products and services that provide information about GHG emissions. A

109 https://www.icos-cp.eu/
110 https://www.actris.eu/
111 http://agage.mit.edu/
112 https://ares-observatory.ch/
113 https://www.coco2-project.eu/
114 https://corso-project.eu/

first example is the Global Carbon Project, which provides an atlas of global GHG emissions[115] based on currently available data. To maximize the value of the global maps of GHG emissions need to be combined with additional socioeconomic and environmental data. For example, machine-learning models can be used for downscaling satellite images as demonstrated for example for air pollution maps (de Hoogh et al., 2019; Kim et al., 2021). Likewise, machine-learning models can be developed to obtain information about consumption-based emissions and product carbon footprints (see Case Study #1, Section 8.2).

8.3.4 Recommendations to Enable Accurate Greenhouse Gas Emission Monitoring

The global GHG monitoring system will be an important tool for monitoring the progress towards a net-zero society. The development of such models requires access to socioeconomic and environmental datasets as well as access to high performance computers.

The European Copernicus program is currently leading the development of GHG monitoring systems with the upcoming CO2M satellite constellation and the GHG monitoring system implemented in CAMS. Access to Copernicus services will be essential if Switzerland is to continue to participate in developments in this area.

The development of the GHG monitoring systems is strongly driven by the research community through international project (e.g., Horizon Europe) and the implementation is funded international organizations such as ESA, EUMETSAT and ECMWF through the European Commission and thus is limited to Copernicus member states. Since Switzerland is currently not a member, Swiss researchers and companies cannot compete in calls for tenders.

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