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2nd Swiss National GAW/GCOS Symposium 2026 White Paper

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Executive Summary

The Swiss National GAW/GCOS Symposium 2026 brought together more than 100 experts to review progress since the last Symposium in 2021 and to identify priorities for the coming years. The symposium confirmed Switzerland's strong contribution to the WMO Global Atmosphere Watch (GAW) and Global Climate Observing System (GCOS) programmes and highlighted the continued importance of coordinated long-term Earth system observations.

The presentations demonstrated major progress in integrating in-situ observations, remote sensing, modelling, and data science and AI/ML approaches, while advancing societally relevant applications related to urban climate, glacier retreat, drought monitoring, biosphere-atmosphere interactions, and atmospheric composition changes. A central outcome of the symposium was the reaffirmation that sustained long-term observations remain the foundation of robust climate and atmosphere research. Continuous, high-quality observational records are essential for detecting environmental change, validating emerging measurement techniques and AI-based approaches, and ensuring reliable climate services and policy-relevant information at national and global levels. Safeguarding the continuity, quality, and long-term sustainability of observing systems therefore remains the highest strategic priority of the programmes.

The symposium also highlighted the growing importance of integrating remote sensing, process-relevant observations, modelling, and AI/ML approaches with in-situ observations. Advances in data science and machine learning offer major opportunities for improved analysis, prediction, and service development. However, the application of these novel approaches requires rigorous validation against high-quality reference observations and depend on accessible, interoperable, and well-documented data infrastructures.

Another key finding was the growing importance of translating observations into actionable climate services and decision-support products. Effective knowledge transfer requires stronger engagement with stakeholders and users, co-development of services, and communication approaches tailored to societal needs. This is particularly relevant for Switzerland as an Alpine country, where climate change impacts are amplified and adaptation needs are increasing rapidly.

Overall, the Symposium 2026 demonstrated that the progress presented by the Swiss GAW and GCOS communities was well in line with the recommendations formulated in the White Paper 2022. Given their long-term strategic nature, all recommendations remain relevant and valid, while the discussions at the symposium also highlighted emerging priorities and led to the following four strategic recommendations for the future development of Swiss GAW and GCOS activities:

High-quality long-term observations: Ensuring the continuity of high-quality long-term observations is of fundamental importance, as they provide the essential ground-based reference ("ground

truth") for the validation, calibration, and long-term consistency assessment of emerging measurement techniques, remote sensing products, and model outputs. This requires i.a. rigorous, cutting-edge science. In addition, these activities should be complemented by an agile scientific component that enables timely responses to new developments in measurement methods (such as advances in instruments or data analysis techniques), emerging trends, and processes that are currently under-explored. At the same time, the long-term sustainability of Swiss observing systems should be regularly assessed, including the prioritization of observation sites and variables, in order to ensure that available resources are focused on scientifically and societally most relevant observations.

Data management and integration: Quality control, homogenization, traceability, and comprehensive documentation for global-, regional-, and national-scale measurements remain critically important and must be ensured in the long term. Related data and metadata need to be stored/archived in curated and trustworthy repositories and ideally in interoperable data ecosystems. In addition, regular re-evaluation of historical datasets is essential to enhance their stability, robustness, and long-term consistency and compatibility. Progress towards more comprehensive observation coverage should be achieved by systematically extending in-situ monitoring through the integration of process-relevant and remote sensing data and/or through the integration of observations based on simplified techniques with (sparse) high-quality observations in blended, tiered networks. A more encompassing and comprehensive data management is a prerequisite for efficient inclusion of diverse data sets in AI/ML analysis frameworks. Strengthening the integration between in-situ observations, remote sensing products, modelling, and reanalysis frameworks is essential to improve spatial and temporal coverage and to enable robust cross-validation of datasets. This attributes particular value to data obtained in under-observed regions, such as the cryosphere and high-mountain areas.

Knowledge transfer and science for services: There is a clear need to strengthen the transfer of knowledge from science to society, ensuring effective connections across the full chain from observations and research to climate services and communication. This is especially relevant for mountainous countries like Switzerland, where the warming is roughly twice as high as in the global average and impacts are likely to be more severe. A key priority is to more clearly demonstrate the impact of scientific findings and to strengthen the translation of scientific results into policy-relevant actionable information, thereby enhancing the interface between monitoring, science, and decision-making. Effective climate services require early and continuous engagement with relevant stakeholders and users in order to better identify needs, co-develop services, and improve usability and societal relevance of scientific information. In parallel, knowledge transfer represents a significant opportunity for international cooperation and capacity development.

Interdisciplinary and cross-institutional collaboration: Next-generation numerical weather and climate prediction models are now complemented by AI/ML models and should be recognised, utilised, and further developed as key platforms for interdisciplinary collaboration. Data science can play a key part in enabling stronger integration across observational and modelling communities, crucial to better describe and understand the Earth System. Joint efforts remain necessary to ensure the continued development and long-term sustainability of existing observing systems, as well as to address and close critical measurement gaps.

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1 Introduction

1.1 Context and Motivation

Based on the WMO Global Atmosphere Watch (GAW) programme launched in 1989, and the co-sponsored Global Climate Observing System (GCOS) programme launched in 1992, the Swiss Federal Council has mandated MeteoSwiss to implement these two programmes at the national level, respectively in 1994 and 2006 (BBI, 2002). The goal of this engagement is to contribute to the global-scale systematic observation of the chemical composition of the atmosphere as well as of a large number of essential climate variables (ECVs). MeteoSwiss as the host of the Swiss GAW/GCOS Office coordinates the implementation of the programmes on a national level through a network of national partners. Today, the GAW and GCOS programmes remain important, but are challenged by limited funding at the WMO and countries' levels, not least in Switzerland. Also, the climate priority is overshadowed by geopolitical crises which further jeopardizes an adequate level of funding for monitoring efforts such as GAW and GCOS. The Swiss contribution to GAW and GCOS has been substantial and important throughout the existence of these programmes, and it is all the more important for this contribution to be maintained and be made as targeted and effective as possible.

The Swiss National GAW/GCOS Symposium aims to provide a dedicated platform for the Swiss GAW and GCOS communities to exchange knowledge and ideas and to present progress achieved in recent years. One important objective of the symposium is to identify the strategic priorities for both national programs for the forthcoming period which are published in the form of the present White Paper. The first one was published in 2022, followed by this updated edition. This process ensures the coherent and continuous advancement of the Swiss GAW and GCOS strategies in alignment with the international GAW Science and Implementation Plan and the GCOS Implementation Plan. Relating to the GCOS-CH programme, the present White Paper supersedes the GCOS Switzerland Strategy 2017–2026 (MeteoSwiss, 2017) beyond 2026.

1.2 GAW-CH in Brief

Launched in 1989, the Global Atmosphere Watch programme (GAW) is a partnership of about 100 countries to monitor the composition of the atmosphere. The programme supports a global network of high-quality monitoring stations measuring greenhouse gases, ozone, UV radiation, aerosols, reactive gases and precipitation chemistry with high accuracy and worldwide comparability. The GAW Science and Implementation Plan (WMO, 2025) provide the international guidelines for the Swiss GAW programme (GAW-CH). The Swiss GAW/GCOS Office at MeteoSwiss coordinates and supports around a dozen institutions including long-term monitoring, research, and the operation of central calibration and quality-assurance facilities for the global network.

1.3 GCOS-CH in Brief

The Global Climate Observing System (GCOS) was established in 1992 to coordinate global climate observation and to ensure that users have access to the data and information needed to address climate-related challenges. Today, within the framework of GCOS-CH, high quality data on 34 Es-

sential Climate Variables ECVs are being continuously collected, processed and made publicly available (MeteoSwiss, 2025). GCOS-CH also includes seven international calibration and data centers. The systematic observation of ECVs and the operation of international centres in Switzerland are enabled through the collaborative efforts of numerous national partner institutions and is coordinated by the Swiss GAW/GCOS Office at MeteoSwiss. The GCOS 2022 Implementation Plan (WMO, 2022) provides the international framework for actions to be implemented by the entirety of the Swiss GCOS community.

2 Goal & Structure of the Symposium 2026

The main objectives of the Symposium 2026 were to bring together the Swiss GAW and GCOS communities to share and report on recent developments and progress, while also introducing a new generation of scientific leadership within both communities. The event aimed to identify gaps in systematic climate and atmospheric chemistry observations, as well as to evaluate the strengths and opportunities within the national scientific community. In addition, the symposium sought to spark innovative ideas across the broader Swiss GAW and GCOS landscape and, building on the recommendations outlined in the White Paper 2022 (MeteoSwiss, 2022), to identify emerging challenges.

Recommendations of the 1st Swiss National GAW/GCOS Symposium

In 2022, the main recommendations to the Swiss GAW and GCOS communities were (MeteoSwiss, 2022):

Innovation and silo-breaking collaboration across cycles: Exploration of new approaches and methods should be facilitated more strongly. Also, joint efforts are needed to ensure the continued development of existing observing systems and ideally to close critical measurement gaps. Next-generation numerical weather and climate prediction models simulate an increasing number of Earth System elements and should be recognized, utilized and exploited as a natural platform for collaboration.

Approaches to constrain individual and overall fluxes and processes: Overall fluxes within the carbon, energy and water cycles should be explored individually, but also across the cycles. This will help close their balance globally by reducing sources of uncertainties and identifying calibration and reprocessing needs. New types of uncertainties arise with the possibility of thresholds or tipping points that might be reached under further global warming. Early warning systems can only be designed on the basis of robust and long-term observations. Targeted analyses on a specific focus across all cycles, for example, on mountain areas, should be pursued. This requirement is complementary to single ECV observation studies but could be supported through GAW or GCOS.

Data maintenance and sustainability: Quality control, traceability and a sound documentation for global-, regional- and national-scale measurements are critically important and must be assured continually. In addition, the importance of regular reevaluation of historical data sets is important in order to increase their stability and robustness and guarantee their best possible consistency and compatibility.

Data integration and research: Progress towards a more comprehensive observation coverage should be sought by improving the link between the in-situ, remote sensing, modelling and re-analysis communities. Achievement of a global-scale balance for carbon, energy and water fluxes, cross validation of datasets, and the definition of observational requirements should be performed at different scales, possibly with the help of the setup and promotion of supersites. The cryosphere is notoriously underobserved at the global scale, especially in high-mountain areas.

Knowledge transfer: There is the clear need to transfer knowledge from science to society, and questions remain how to connect the full range from observations and science via climate services to climate communication. ‘Climate Indicators’ should play a more prominent role for creating such a dialogue; hence the recommendation to extend the current set of GCOS Global Climate Indicators. Knowledge transfer, especially to less developed countries around the globe, is a great opportunity for making the GAW and GCOS programmes more valuable at the global scale. New avenues to most efficiently transfer and export knowledge should be explored.

The Symposium brought together over 100 participants and provided a valuable platform for the exchange of knowledge and ideas. The programme featured two keynote lectures, 16 presentations structured in four main sessions, along with around 30 poster presentations. The detailed programme along with short summaries of each presentation is provided in Annex A and Annex B, respectively.

The first session focused on recent progress since the White Paper 2022, including presentations of four projects funded by the call for proposals in 2022. The second session addressed the increasing importance of Earth system data, with speakers emphasizing the crucial role of comprehensive, long-term datasets in understanding and predicting environmental change. Following a significant turnover in the Swiss GAW/GCOS communities in recent years, the third session was dedicated to giving a new generation of scientific leadership the opportunity to present themselves and their scientific plans and contributions to the programmes. Finally, the fourth and last session highlighted the use of Earth system data for impactful applications, to showcase advances in data integration and analysis, and demonstrate how high-quality data can support climate research and inform environmental policy. The programme was enriched by two keynote presentations of an established and an upcoming service provider, i.e. Laurence Rouil, Director of the Copernicus Atmosphere Monitoring Service (CAMS) run by ECMWF on “AI/ML – from Numerical Weather Prediction to Atmospheric Composition Forecasting, a Game Changer”, and Felix Seidel, Managing Director of ETH Swiss GeoLab on the plans of the “ETH Swiss GeoLab: Transforming Earth Observation into Action”.

A high-level panel discussion complemented the programme, bringing together representatives from the top management of major Swiss environmental institutions to share their perspectives.

Figure 1: Participants of the 2nd Swiss National GAW/GCOS Symposium, Day 2 © MeteoSwiss

3 Sessions

3.1 Keynote presentations

3.1.1 AI/ML - from NWP to atmospheric composition forecasting, a game changer - Laurence Rouil, Director of CAMS, ECMWF

Laurence Rouil illustrated that ECMWF has achieved world-leading numerical weather prediction (NWP) through sustained advances in data assimilation, model physics, and high-performance computing, combined with strong international collaboration. A key success factor has been the systematic use of global observations—especially satellite data—to provide high-quality initial conditions for forecasts. The steady progress ECMWF was able to sustain over the last decades reflects the unique integration of research and 24/7 operations, enabling rapid transition from scientific innovation to operational benefit.

Building on this foundation, ECMWF, on behalf of the European Commission, have established the Copernicus Services for climate change (C3S) and atmospheric composition monitoring (CAMS). C3S in particular, brought forth the ERA5 reanalysis, a comprehensive global data going back to 1940. This data set gave rise to various private sector AI-driven prediction models that showed surprising forecast skills out to ten days and beyond. ECMWF, through a targeted effort has successfully established its leadership also to AI-based forecasting, a technique that dramatically reduces computational costs and runtimes, once a model is trained on observations and reanalyses.

Looking ahead, hybrid approaches combining physical modelling and AI are expected to deliver further gains. In this context, AI-based methods are also developed for CAMS and are highly promising for atmospheric composition forecasting, enabling improved representation of air pollution and chemical processes while enhancing efficiency and supporting new applications.

3.1.2 ETH Swiss GeoLab - Transforming Earth Observation Into Action - Felix Seidel, Managing Director, ETH Swiss GeoLab

Using the example of the relationship between snow cover in the San Francisco region and the availability of hydropower and drinking water, Felix Seidel illustrated the core ambition and added value of the ETH Swiss GeoLab. By regularly monitoring snow cover at high resolution through remote sensing data and combining it with conventional measurements, authorities can make better-informed decisions in balancing water supply and hydropower needs. In the presented case, such optimization led to savings in the tens of millions, highlighting the goal of delivering “sustainable services to the community.”

ETH Swiss GeoLab intends to focus primarily on application areas such as landslides, avalanches, wildfires, and droughts. Switzerland is seen as an ideal location, as few regions offer such a dense network of high-quality in-situ measurements. This provides a unique opportunity to combine these data with Earth observation (EO) data, particularly through the use of AI and machine learning. How-

ever, it was emphasized that the already vast and rapidly growing data volumes must be better utilized, for example through the development of data lakes.

GeoLab aims to follow a customer-driven innovation process, starting from user requirements and progressing through product development to market readiness. The approach can be summarized as moving “from user needs to market” and delivering individual solutions to specific challenges, with the potential emergence of start-ups being explicitly welcomed. Existing data and products, especially from Copernicus, will be integrated, but require further refinement to suit Switzerland’s specific natural conditions.

3.2 Recent Progress based on the White Paper 2022

Summary compiled by Martin Steinbacher, Empa

The session showcased four recently funded Swiss GAW/GCOS projects – the Swiss H2O Hub, TapRep, SwissPhenocam, and UrbaNature – which together illustrated substantial progress toward the ambitions outlined in the White Paper 2022 (MeteoSwiss, 2022). A common theme across all contributions was the strong emphasis on innovation and silo-breaking collaboration. Each project involved multiple institutions and demonstrated how interdisciplinary partnerships can close observational gaps and strengthen Switzerland’s role in integrated Earth system monitoring.

All presentations highlighted the effective combination of in-situ and remote sensing data, directly supporting the recommendation on data integration and research. Examples included the use of novel balloon-borne in-situ and ground-based remote sensing water vapour observations, the exploitation of Swisstopo’s repeat aerial imagery for glacial and periglacial studies, and the use of webcam networks for continental-scale phenology tracking. These approaches illustrated the increasing ability to merge datasets across spatial and temporal scales as well as across scientific domains.

A recurring message was the critical role of long-term monitoring and repeated measurement campaigns. Speakers stressed that sustained observations are essential both for capturing sudden events such as the Hunga Tonga eruption, as well as for documenting slow, climate-driven changes. This directly ties into the White Paper 2022 (MeteoSwiss, 2022) recommendation for approaches to constrain fluxes and processes, where continuity, calibration, and methodological consistency are key. The session also underlined that the integration of new detection techniques requires careful evaluation to maintain long-term data consistency.

Across projects, the importance of timely data release, accessible documentation, and targeted communication emerged clearly. Participants noted that maximizing the visibility and utility of datasets requires tailored outreach to specific user groups and stakeholders. This issue was also brought up in the fourth session on Earth System Data for Impactful Applications. The need for robust, long-duration time series was additionally connected to the rapidly growing field of AI applications, for which high-quality reference data are indispensable.

Two areas identified in the White Paper 2022 (MeteoSwiss, 2022), data maintenance & sustainability, and knowledge transfer, received comparatively less attention in the project presentations, which is understandable given their focus on current scientific progress rather than long-term operationali-

zation. Nevertheless, discussions suggested that evaluating the societal and economic value of monitoring activities remains desirable, even if difficult to quantify.

Overall, the session demonstrated that the projects funded since the White Paper 2022 (MeteoSwiss, 2022) are strongly aligned with its scientific priorities, particularly regarding collaboration, integration of diverse observational systems, and the need for sustained, high-quality monitoring.

3.3 Increasing Importance of Earth System Data

Summary compiled by Isabelle Gärtner-Roer, University of Zurich

In view of the White Paper 2022 (MeteoSwiss, 2022), clear links to the recommendations made in 2022 were presented in the session “Increasing Importance of Earth System Data”. Several presentations on Earth observation showed new monitoring and modelling approaches. Interesting and useful combinations of remote-sensing products with in-situ observations were shown (link to recommendation data integration and research). This indicates that a huge effort and progress was made during the last years in integrating remote-sensing data into analyses, e.g. to derive global glacier mass change. Nevertheless, the existence of long-term in-situ observations is very important for validation and for careful evaluation of the different data sets. Hence, it was emphasized several times that the existence of accurate, reliable, and continuous data is key and needs to be one key priority also in the future. Further, the data needs to come with correct documentation and data quality assessments (link to recommendation data maintenance and sustainability). Links to GCOS ECVs were explicitly mentioned in several presentations and indicate the need for process understanding and links to related fluxes and processes, but also the need to present the data and observations in a way that they are useful for science and policy (link to recommendation knowledge transfer). In this context, especially the presentation of the “Swiss data cube” by Gregory Giuliani was interesting regarding clear tracks from data to understanding by collaborative approaches and even linking to (cantonal and federal) policies.

Impressive examples of applications in machine learning, deep learning and AI approaches were shown. In some thematic areas, the use of these novel approaches seems to have become established, with useful results and with an increasingly fast development, while other areas still need to catch up. Either way, a critical assessment including ethics and best practices is timely and important for the near future.

In this second session, the recommendation knowledge transfer was not addressed in depth, which was probably related to the topic of the session. But it needs to be stated clearly that there is a need to put more effort into linking different projects on related topics (within Switzerland and globally) as well as science to society and decision makers.

3.4 New Generation of scientific leadership in GAW-CH/GCOS-CH

Summary compiled by Martin Gysel-Beer, PSI

This session provided a platform for emerging research activities and new researchers that started after publication of the GAW/GCOS White paper in 2022.

Dr. Claudia Mohr, Head of the Laboratory of Atmospheric Chemistry (LAC) at PSI and Professor for Aerosol Chemistry at ETH Zürich, has a research focus on atmosphere-biosphere interactions to assess how the chemical and physical interplay of biogenic and anthropogenic emissions in the atmosphere results in impacts on weather and climate as well as air quality and human health. Striving for understanding across scales, the LAC performs long-term observations providing context and trends, intensive field experiments providing comprehensive characterization of atmospheric composition and phenomena, and experiments at an atmospheric chemistry simulation chamber under well-constrained conditions providing detailed process understanding. In addition, there is need for capacity building to enable observations in underexplored regions. Better integration of in situ observations, remote sensing and modelling, facilitated by recent progress in data science and open data provision, offers many opportunities.

Dr. Eliza Harris, Professor for Climate and Environmental Physics at the University of Bern and Director of the Foundation for the High Altitude Research Stations Jungfraujoch and Gornergrat, presented the opportunities and challenges associated with isotopic measurements of greenhouse gases at mountain sites. Background and baseline stations allow investigation of large-scale changes in atmospheric processes and biogeochemical cycles, e.g. to understand the contributions of sources, sinks and processes to acceleration of the increasing trend of N2O mixing ratio in the atmosphere. While major progress has been made in recent years with experimental methods, modelling transport of emissions inside the atmospheric boundary layer to the lower free troposphere probed at mountain sites remains a challenge.

Dr. Timofei Sukhodolov, Head of the Climate Group at the Physical-Meteorological Observatory Davos / World Radiation Centre PMOD/WRC, presented likely but unpleasant scenarios for the future atmosphere altered by episodic natural or new anthropogenic emissions. Observational data acquired during and after past volcanic eruptions are an important testbed to improve process understanding and modelling of the impacts of future major eruptions. Substantial progress has been made in simulating stratospheric dynamics and composition, however, some processes remain a challenge or understudied, therefore requiring both simulations and experimental studies covering all scales. This is particularly important in view of drastically increasing emissions from rocket industry or hypothetical climate interventions using stratospheric aerosol injections for solar radiation management. Continuous monitoring of atmospheric composition including ozone is crucial to detect early signs of unforeseen chemical side effects.

Dr. Benjamin Stocker, Professor for Geocomputation and Earth Observation at the University of Bern, presented his research on anomaly detection for drought impact monitoring of Swiss forests. Switzerland is exposed to a high risk of hazardous summer droughts with a wide range of impacts on e.g. ecosystems and food production. Multi satellite-borne remote sensing methods are used to develop drought monitoring and early warnings with good spatio-temporal coverage based on deviations from statistically expected seasonal cycles of forest greenness levels, which is closely related to vegetation productivity. The basis for communicating drought levels is built, while achieving a physically consistent state estimate for multiple connected climate variables remains an open research field. New partnerships are needed for expanding the monitoring to grassland and croplands or to implement near-term forecasting of droughts.

3.5 Earth System Data for impactful applications

Summary compiled by Iris Feigenwinter, ETH Zurich

The last session of the symposium was about how data can be translated into a service, be it in the form of GHG inventories, Swiss climate scenarios, natural hazard predictions in alpine regions, or a national early warning system for drought. All the talks in this session related most to the White Paper 2022 (MeteoSwiss, 2022) recommendation of knowledge transfer but also covered aspects of the other recommendations. Knowledge transfer was discussed in different forms, e.g. in a more scientific/collaborative context with identifying missing emissions sources or setting up a measurement station in Bhutan but also how to communicate findings which can ultimately help to support decision-making. For example, the Swiss climate scenarios use images of people that live in different versions of a future world to make their findings more accessible, and a user-centered approach was used for the website design of the national drought early warning system. Thus, it is important to consider who the stakeholders are when creating a data product/service and many steps are necessary, including data interpretation and dissemination, until we get from science to services. Interdisciplinary approaches and collaboration between different institutions made the creation of these services possible. The resulting data products should be open and freely available to the users, following FAIR (findable, accessible, interoperable, reusable) principles.

What all the talks from this session had in common was that they highlighted the importance of long-term in-situ measurements, which directly links to one of the main aims of GCOS. These measurements are important not only in Switzerland but also across borders, e.g. for atmospheric transport models, highlighting the relevance of international research infrastructures such as ICOS or ACTRIS. Data maintenance and sustainability and data integration and research are therefore still valid recommendations. New opportunities for measurements were also presented, e.g. drones in steep alpine regions where satellite methods reach their limits or a new cosmic ray sensor for snow water equivalent estimates. Challenges identified were that there are still uncertainties in the models (e.g. about emission sources and sinks), and maintaining the long-term measurements might get more difficult in the future due to practical reasons such as danger from thawing permafrost during station visits but also financial reasons as the long-term funding of stations is not always secured.

Overall, this session showed that Switzerland already has a lot to offer in terms of climate data products and services. However, continued efforts are still required, be it to update the models with the most recent observations, to maintain the long-term measurement stations, to measure additional variables (ECVs), or to make climate services available to many kinds of users.

3.6 Panel Discussion

A high-level panel discussion concluded the Symposium. Representatives from the top management of Swiss partner institutions summarized and consolidated the main outcomes and recommendations that emerged from the preceding two days. Stefan Brönnimann, Chair of the Swiss GAW/GCOS Scientific Steering Committee, moderated the discussion. The panel members were Martin Ackermann, Director of Eawag, Brigitte Buchmann, President of Federal Commission for Air Hygiene, Ulrike Lohmann, Professor at ETH Zurich, Laurence Rouil, Director of CAMS, ECMWF, Felix Seidel, Managing Director of ETH Swiss GeoLab, Stefan Uhlenbrook, Director of MeteoSwiss.

The panel discussion highlighted Switzerland's significant contributions to both international programmes, underscoring a strong sense of national commitment and leadership.

A central theme was the unique position of Switzerland in maintaining long-term observational time series. These were repeatedly described as a foundational asset, forming the backbone of scientific understanding and international contributions. The panel stressed the importance of safeguarding these time series in the future, noting that their continuity is essential to sustaining impact and credibility.

The diversity of the Swiss GCOS and GAW activities was identified as a key strength, providing an ideal "test bed" for the development and implementation of innovative approaches. This diversity enables experimentation and methodological advancement, positioning Switzerland as a valuable contributor to the evolution of the global programs.

At the same time, participants agreed that international integration is becoming increasingly important. Strengthening connections with global frameworks and initiatives was seen as critical to ensuring relevance, visibility, and continued influence.

A recurring point concerned the need to better articulate and demonstrate the societal and policy relevance of scientific activities. While the potential to generate value is widely acknowledged, the translation of scientific findings into policy-relevant actions remains a challenge. The panel highlighted that ultimately, impact must be demonstrated more clearly.

Finally, the discussion touched on the balance between interdisciplinary collaboration and disciplinary depth. While interdisciplinary approaches were broadly supported, it was also noted that strong, discipline-specific fundamental research conducted within more focused contexts remains essential. Such work provides the necessary foundation for subsequently integrating new insights into a broader, interdisciplinary framework.

Overall, the discussion remained at a high level, but it clearly pointed to key strategic priorities, including the safeguarding of long-term observations, strengthening international linkages, and enhancing the policy relevance and impact of scientific activities.

4 Conclusions and Recommendations for Future Activities

4.1 Conclusions

The Swiss National GAW/GCOS Symposium 2026 provided an opportunity to reflect on selected achievements and developments over the past four years and to discuss priorities and strategic directions for the next four-year period. The progress presented at the symposium was largely aligned with the recommendations of the White Paper 2022 (MeteoSwiss, 2022), particularly with respect to:

- reaffirming the critical importance of sustained, high-quality long-term observations, for validating emerging methodologies and documenting climate variability and change. Ensuring the continuity and sustainability of these observation systems remains a challenging key priority;
- strengthening the integration of in-situ observations with remote sensing observations and other innovative, process-relevant observations to improve the understanding of Earth system processes across spatial and temporal scales;
- reinforcing coordinated, interdisciplinary and cross-institutional collaboration to address complex scientific questions and to strengthen contributions to international Earth system monitoring frameworks;
- translating observational data into actionable information and services, particularly to support climate services and evidence-based decision-making.

At the same time, the symposium highlighted emerging priorities and persistent challenges:

- emerging techniques, particularly machine learning and AI were identified as important drivers of innovation. Their application requires careful evaluation to ensure consistency with existing long-term datasets and to maintain scientific robustness. AI is clearly a very versatile methodological framework which constitutes a vast playground for collaborations, effectively enabled by data sciences. At the same time data management, including AI-ready access, becomes increasingly important;
- Effective knowledge transfer depends on user- and even customer-oriented approaches, clear communication, and adherence to TRUST and FAIR data principles. Further efforts are needed to strengthen the interface between science, policy, and society, and to improve coordination among related initiatives at national and international levels;
- Overall, the symposium reaffirmed that high-quality, well-documented, and FAIR data generated by sustained observation systems, remain the foundation for both scientific progress and evidence-based policy.

4.2 Recommendations

In conclusion, and with reference to the recommendations of the Symposium in 2021 (MeteoSwiss, 2022), the following thoughts were offered to the Swiss GAW and GCOS programmes for consideration in their current and future implementation efforts:

High-quality long-term observations: Ensuring the continuity of high-quality long-term observations is of fundamental importance, as they provide the essential ground-based reference ("ground truth") for the validation, calibration, and long-term consistency assessment of emerging measurement techniques, remote sensing products, and model outputs. This requires i.a. rigorous, cutting-edge science. In addition, these activities should be complemented by an agile scientific component that enables timely responses to new developments in measurement methods (such as advances in instruments or data analysis techniques), emerging trends, and processes that are currently under-explored. At the same time, the long-term sustainability of Swiss observing systems should be regularly assessed, including the prioritization of observation sites and variables, in order to ensure that available resources are focused on scientifically and societally most relevant observations.

Data management and integration: Quality control, homogenization, traceability, and comprehensive documentation for global-, regional-, and national-scale measurements remain critically important and must be ensured in the long term. Related data and metadata need to be stored/archived in curated and trustworthy repositories and ideally in interoperable data ecosystems. In addition, regular re-evaluation of historical datasets is essential to enhance their stability, robustness, and long-term consistency and compatibility. Progress towards more comprehensive observation coverage should be achieved by systematically extending in-situ monitoring through the integration of process-relevant and remote sensing data and/or through the integration of observations based on simplified techniques with (sparse) high-quality observations in blended, tiered networks. A more encompassing and comprehensive data management is a prerequisite for efficient inclusion of diverse data sets in AI/ML analysis frameworks. Strengthening the integration between in-situ observations, remote sensing products, modelling, and reanalysis frameworks is essential to improve spatial and temporal coverage and to enable robust cross-validation of datasets. This attributes particular value to data obtained in under-observed regions, such as the cryosphere and high-mountain areas.

Knowledge transfer and science for services: There is a clear need to strengthen the transfer of knowledge from science to society, ensuring effective connections across the full chain from observations and research to climate services and communication. This is especially relevant for mountainous countries like Switzerland, where the warming is roughly twice as high as in the global average and impacts are likely to be more severe. A key priority is to more clearly demonstrate the impact of scientific findings and to strengthen the translation of scientific results into policy-relevant actionable information, thereby enhancing the interface between monitoring, science, and decision-making. Effective climate services require early and continuous engagement with relevant stakeholders and users in order to better identify needs, co-develop services, and improve usability and societal relevance of scientific information. In parallel, knowledge transfer represents a significant opportunity for international cooperation and capacity development.

Interdisciplinary and cross-institutional collaboration: Next-generation numerical weather and climate prediction models are now complemented by AI/ML models and should be recognized, utilised, and further developed as key platforms for interdisciplinary collaboration. Data science can

play a key part in enabling stronger integration across observational and modelling communities, crucial to better describe and understand the Earth System. Joint efforts remain necessary to ensure the continued development and long-term sustainability of existing observing systems, as well as to address and close critical measurement gaps.

Abbreviations

ACTRIS	Aerosol, Clouds and Trace Gases Research Infrastructure
AI	Artificial Intelligence
CAMS	Copernicus Atmospheric Monitoring Service
ECMWF	European Centre for Medium-Range Weather Forecasting
ECV	Essential Climate Variable
Empa	Swiss Federal Laboratories for Material Science and Technology
EO	Earth observation
EUMETSAT	European Organisation for the Exploitation of Meteorological Satellites
FAIR	Findable, Accessible, Interoperable, Reusable
FOEN	Federal Office for the Environment
GAW	Global Atmosphere Watch
GAW-CH	Swiss implementation of the GAW programme
GCOS	Global Climate Observing System
GCOS-CH	Swiss implementation of the GCOS programme
GHG	Greenhouse gas
ICOS	Integrated Carbon Observation System
IPCC	International Panel on Climate Change
LAC	Laboratory of Atmospheric Chemistry at PSI
NWP	Numerical Weather Prediction
PMOD/WRC	Physikalisch-Meteorologisches Observatorium Davos/World Radiation Center
PSI	Paul Scherrer Institute
SLF	WSL-Institut für Schnee- und Lawinenforschung
TRUST	Transparency, Responsibility, User focus, Sustainability, and Technology
WGMS	World Glacier Monitoring Service
WMO	World Meteorological Organization
WSL	Eidg. Forschungsanstalt für Wald, Schnee und Landschaft

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Acknowledgement

We extend our sincere gratitude to the Scientific Programme Committee of the Symposium for their dedicated support of the Swiss GAW/GCOS programmes throughout the preparatory phase and conference. Their expertise provided the foundation for much of the scientific content of the White Paper. We also warmly thank the contributing scientists for their thoughtful reviews, with particular appreciation to Stefan Brönnimann and the whole Swiss GAW/GCOS Scientific Steering Committee as well as Mischa Croci-Maspoli for their insightful comments on the final manuscript.

We are grateful to all the speakers for their substantial contributions to the Symposium, as well as to the distinguished high-level panel for fostering a stimulating and insightful discussion. Special recognition is due to the Haus des Sports in Ittigen near Bern for their exemplary professionalism and hospitality. Finally, we wish to convey our gratitude to the Swiss GAW/GCOS communities, whose active participation and sustained engagement ensured the Symposium's success and marked an important step for Earth System Science in Switzerland.

Appendices

A Symposium Programme

Day 1 – Wednesday, 25th March 2026

9:00		Arrival and Welcome Coffee
9:45	Opening Session	**Welcome** Petra Zimmermann, MeteoSwiss Stefan Brönnimann, Chair Swiss GAW/GCOS Scientific Steering Committee
		Housekeeping
		Update from the GAW Secretariat Poalo Laj, WMO
		Update from the GCOS Secretariat Antonio Bombelli, WMO
		Keynote: AI/ML – from NWP to atmospheric composition forecasting, a game changer Laurence Rouil, Director of CAMS, ECMWF
11:25	Recent Progress Based on the White Paper 2022	**The Swiss H2O Hub: High-quality water vapor measurements from ground to space** Gunter Stober, University of Bern
		The rapid decline of Swiss glaciers: Monitoring needs and potential Matthias Huss, ETH Zurich
		SwissPhenocam: Country-scale automated phenology tracking Jan Dirk Wegner, University of Zurich
		Feedbacks between vegetation, carbon, energy, and water cycles in the urban environment: recent advancements from the UrbaNature project Stavros Stagakis, University of Basel – Dominik Brunner, Empa
13:15		Lunch Break / Poster Session
15:00	Increasing Importance of Earth System Data	**Monitoring anthropogenic emissions of air pollutants and greenhouse gases from space** Gerrit Kuhlmann, Empa
		High-resolution lake ECV monitoring for the Alpine region Michael Brechbühler, Eawag
		Some reflections on glacier dynamics observations in remote sensing datasets based on studies of one of the WGMS reference glaciers Martin Hoelzle, University of Fribourg
		From the Swiss data cube to living Switzerland: Developing a digital twin of the environment Gregory Giuliani, University of Geneva
16:40		Wrap-Up and Main Findings Day 1
17:00		Ice Breaker

Day 2 – Thursday, 26th March 2026

8:45		Arrival and Welcome Coffee
9:30	Opening Day 2	**Keynote: ETH Swiss GeoLab – Transforming earth observation into action** Felix Seidel, Managing Director, ETH Swiss GeoLab
10:05	New Generation of Scientific Leadership in GAW-CH/ GCOS-CH	**Relevance of long-term observations and controlled lab studies for insights into air quality, weather and climate effects of aerosols and precursor gases** Claudia Mohr, PSI
		Greenhouse gas and isotope measurements at the Jungfraujoch research station Eliza Harris, University of Bern
		Likely but unpleasant scenarios of the future atmosphere: geoengineering, rockets, and volcanic eruptions Timofei Sukhodolov, PMOD
		Anomaly detection for drought impact monitoring of Swiss forests Benjamin Stocker, University of Bern
11:45		Lunch Break / Poster Session
13:15	Earth System Data for Impactful Applications	**From atmospheric observations to validation of greenhouse gas emission inventories** Stephan Henne, Empa
		How observations support the development of climate scenarios Regula Mülchi, MeteoSwiss
		The importance of high-mountain cryospheric data for evidence-based decisions – and how to fill the current data gaps: Examples from the Swiss Alps and Bhutan Nadine Salzmann, SLF
		From data to decision support: The Swiss drought early warning and monitoring system Fabia Hüsler, FOEN
14:35		Break
15:10		Wrap-Up and Main Findings Day 2
15:30	Synthesis	**Recap of the main points of the Symposium**
		Reviewing progress, setting priorities – High-level panel discussion Moderation: Stefan Brönnimann, Chair Swiss GAW/GCOS Scientific Steering Committee Martin Ackermann, Eawag – Brigitte Buchmann, Empa – Thomas Frölicher, University of Bern – Ulrike Lohmann, ETH Zurich – Laurence Rouil, ECMWF – Felix Seidel, GeoLab – Stefan Uhlenbrook, MeteoSwiss
16:25		Closing of the Symposium

B Summaries of the Presentations

Paolo Laj - *Update GAW*

The Global Atmosphere Watch (GAW) is WMO's flagship programme on atmospheric composition and its impacts on climate, human health, and the environment. While it is often perceived primarily as a monitoring and research infrastructure network, GAW's role extends far beyond observations. Through the programme, WMO provides its Members with reliable, observation-based information on the state of the atmosphere, complemented by authoritative scientific assessments and advanced tools—including artificial intelligence—to support forecasting and informed decision-making. GAW also underpins international agreements by delivering robust scientific evidence and fosters global capacity through training and knowledge sharing. It addresses key challenges such as strengthening observation networks, tracking the effectiveness of emission reductions, and expanding air quality forecasting services, particularly in underserved regions. Its practical contributions include global monitoring system assessments, stratospheric ozone and air quality reports, and enhanced sand and dust storm forecasting. Switzerland (GAW-CH) plays a pivotal role through research collaboration, operation of key stations, and leadership in data quality and management and in the scientific assessments. Looking ahead, the GAW Next (2028–2031) strategy aims to modernize and expand observing systems, improve global data exchange, and enhance predictive capabilities for environmental hazards. It places strong emphasis on early warning systems, bridging research and operations, and building regional and global capacity, all within a more agile, inclusive, and impact-oriented organizational framework.

Antonio Bombelli - *Update GCOS*

Antonio Bombelli recalled the GCOS Mission (to enhance global climate observations required to monitor and predict climate change, enable science, underpin climate services, and inform policy) and briefly presented the programme and recent updates.
The ECVs (Essential Climate Variables) are undergoing a Rationalization Process to ensure more consistency in terms of their definitions, relevance, regrouping, etc. The process will reduce their number from 55 to 41, with 22 unchanged variables, 19 partially new (resulting from a rearrangement of the existing ones), and 2 removed.
At the last UNFCCC COP30 (Belém, 2025) the GCOS concerns on the threats to systematic observations and limited funding to the GCOS Programme were reflected in the SBSTA-63 conclusions.
The work for preparing the next GCOS Status Report recently started at GCOS-WGClimate-iClimateAction joint meeting, hosted by ESA in Harwell (UK), 9-13 February 2026. The Status Report will highlight gaps in global climate observations (focusing on sustainability, threats to the observing components, single points of failure, risk of inaction) and will be jointly published (in February 2027) with a High Priority Action Plan to address the issues identified by the report itself.
Then the collaboration with the GCOS National Coordinators was presented. Switzerland is among the current 16 members. It was proposed to integrate information from the Swiss GCOS publications (including the new white paper, ECV inventory, etc.) in the next GCOS reports. The relevant Swiss community will be invited to contribute to the public review of these GCOS documents, planned before the end of this year.
The collaboration between GCOS and Switzerland is excellent, and several examples where listed. The accreditation of the Global Terrestrial Network for Glaciers (GTN-G) as GCOS Affiliated Network, in February, was presented as an example of a recent joint achievement. The Swiss GAW/GCOS Office at MeteoSwiss was acknowledged as an effective model to implement GCOS related activities at national level, providing an important contribution to the global observing system for climate.
A possible suggestion to the Swiss GAW/GCOS White Paper is to consider immediate threats – in terms of stability and single points of failure – to the climate (both in-situ and satellite) observing system that may be addressed by the next GCOS reports.

Gunter Stober - *Swiss H2O Hub: Water vapor measurements from ground to the thermosphere*

High-accuracy water vapor measurements are crucial for quantifying Earth's radiative balance and represent a major contributor to the uncertainty budget of the outgoing longwave radiation. The Swiss H2O Hub has developed a suite of dedicated high-quality instruments for both in-situ and remote sensing to obtain water vapor profiles from the ground to space. ALBATROSS, a mid-IR laser spectrometer, provides accurate, high-

resolution, and SI-traceable water vapor data in the upper troposphere-lower stratosphere region. The newly developed Peltier-Cooled Frost Point Hygrometer (PCFH) aims to replace the Cryogenic Frost Point Hygrometer (CFH), which relies on the R23 coolant. The stratospheric observations are complemented by passive radiometers retrieving water vapor profiles in 25-85 km altitude. We demonstrate the performance of the combined instrumentation by detecting the increased water vapor from the Hunga Tunga volcanic eruption.

Matthias Huss - ***The rapid decline of Swiss glaciers: monitoring needs and potential***

Swiss glaciers are melting at an accelerating pace, with far-reaching impacts on mountain hazards, local to regional water availability and global sea-level rise. The programme Glacier Monitoring Switzerland (GLAMOS) delivers consistent long-term data on glacier change with respect to various variables. Results indicate that unprecedented glacier losses have prevailed during the last years. Within the GCOS-funded TapRep project (2023-2024) a suite of interdisciplinary research questions from short-term glacier changes, to impacts on sedimentation processes in the glacier forefield and proglacial lakes and visualization for public outreach have been investigated. Results indicate that the previously underexploited data set of high-resolution orthophotos and DEMs bears are large potential for studying the rapid transformation in glacial environments at a new level of spatio-temporal detail, and for detecting important process-interlinkages.

Jan Dirk Wegner - ***SwissPhenocam: country-scale automated phenology tracking***

The objective of the SwissPhenocam project is to develop and implement an automated phenology monitoring tool that will deliver added-value climate services regarding plant phenological responses to ongoing climate change. To that end, we combine novel deep learning and computer vision methods custom-designed for tree phenology prediction based on an interdisciplinary collaboration between Data Science, Ecology, Weather and Climate Research. All deep learning models are linked to state of the art mechanistic knowledge on phenology as represented in phenology models. We combine reference data collected via in-situ tree phenology observations (via volunteers and our own campaign) with time-series of climate, webcam, and satellite data. All such observations are jointly modeled at Swiss national scale with deep learning approaches that reason across all multi-modal data over time to either, estimate when a certain phenological state happened in the past for an individual tree, or nowcast the current state at present, or to look into the future how phenology will change under a warming climate.

Stavros Stagakis - ***Feedbacks between vegetation, carbon, energy, and water cycles in the urban environment: Recent advancements from the UrbaNature project***

UrbaNature project is entering its final year. The achievements so far include i) the characterization of tree hydraulic strategies across urban density gradients using stable isotope analyses of tree xylem and soil water samples, ii) a new physical based algorithm to reduce shadow effects of urban high resolution remote sensing imagery, iii) a high resolution 3D radiation balance model for urban canyons with trees, and iv) an assessment of ICON-Terra-Urb urban climate simulations using in-situ meteorological data. There are still open questions to address until the end of the project and already planned activities, including field campaigns method and model developments. The final project results are expected to shed more light on the potential of urban vegetation to provide critical services such as improving human thermal comfort. The recent developments in the field indicate that future challenges include the development of common methodological frameworks integrating urban biosphere, climate and GHG emissions, while bridging between different observational and modeling scales.

Gerrit Kuhlmann - ***Monitoring anthropogenic emissions of air pollutants and greenhouse gases from space***

Gerrit Kuhlmann introduced the new generation of satellites that measure air pollutants and greenhouse gases (Copernicus Sentinel-4 and -5 and the CO2M instrument) and demonstrated their importance in monitoring anthropogenic emissions. These satellite measurements will be used in the Copernicus CO_2 emission monitoring and verification support (CO2MVS) service, which is being developed by the European Centre for Medium-Range Weather Forecasts (ECMWF) to support the Paris Agreement on climate change. Several international projects have been conducted in recent years to develop methods for quantifying emissions from countries, regions, cities, and facilities in preparation for this new service. He presented examples from modelling studies

demonstrating the ability to quantify emissions from cities and power plants, as well as showcasing the potential of Sentinel-5P/TROPOMI measurements to validate the location and annual emissions of power plants and industrial facilities within bottom-up point source catalogues. He also demonstrated the importance of the new AVIRIS-4 instrument, which is part of the Swiss ARES observatory, for detecting methane emissions in airborne campaigns. Finally, he demonstrated that, although machine learning models are becoming increasingly important, they depend on accurate simulations based on physics that are validated by measurements from campaigns and long-term records. Understanding processes, methods and their uncertainties is essential for knowledge transfer to society when providing meaningful products and services at international, national and municipal levels.

Michael Brechbühler - ***High-resolution lake ECV monitoring for the Alpine region***

This presentation highlights recent progress in high-resolution monitoring of lake-relevant Earth system variables in the Alpine region. It briefly reviews satellite-observable lake ECVs and the limitations of existing large-scale products for Alpine lakes. A main focus is a new multi-sensor framework for lake ice monitoring, supported by webcam-based calibration and validation, which enables extensive mapping of lake ice cover and phenology for more than 1,200 lakes across the European Alps from 2015 to present. The presentation also introduces Alplakes, a research initiative and data platform linking remote sensing, in-situ observations, meteorological data, and hydrodynamic models to improve lake monitoring and understanding. Together, these activities show how growing EO data resources can strengthen lake monitoring and early warning efforts. They also illustrate the value of combining these multi-source observations and modelling frameworks to better understand lake processes and ecological responses, while supporting interdisciplinary knowledge transfer and broader access for scientists, water professionals, and citizens.

Martin Hoelzle - ***Some reflections on glacier dynamics observations in remote sensing datasets based on studies of one of the WGMS reference glaciers***

Not available

Gregory Giuliani - ***From the Swiss Data Cube to Living Switzerland: Developing a Digital Twin of the Environment***

Living Switzerland tackles Earth System interdisciplinarity by integrating land, climate, biodiversity, and water cycles within a unified, semantically consistent land-cover framework based on multi-source Earth Observation data.
It overcomes siloed approaches through harmonised data infrastructures, linking environmental processes via DPSIR analysis and enabling cross-cycle monitoring, change detection, and scenario modelling with artificial intelligence.
By fostering collaboration across scientific, governmental, and technical domains, it provides a scalable foundation for a Digital Twin of the Swiss Environment and more integrated, evidence-based decision-making.

Claudia Mohr - ***Relevance of long-term observations and controlled lab studies for insights into air quality, weather and climate effects of aerosols and precursor gases***

In this presentation I will briefly present my scientific expertise and the Laboratory of Atmospheric Chemistry (LAC) I lead at Paul Scherrer Institute (PSI). The LAC runs the aerosol in-situ observations of the observational sites Jungfraujoch and Payerne, part of several networks and research infrastructures including GAW/GCOS, and is host to the PSI atmospheric chemistry simulation chamber (PACs). The 30+ years of climate-relevant data from Jungfraujoch are of high importance for the investigation of trends and extreme events such as dust and wildfire events. I will present examples from research and education on these topics, including combining in-situ and remote sensing data, and conclude with suggestions of topics we should address as a community.

Eliza Harris - ***Isotopic measurements of greenhouse gases at mountain sites: Opportunities and challenges***

Isotopic measurements of greenhouse gases at background stations help constrain large-scale atmospheric processes and global biogeochemical cycles. Mountain sites like Jungfraujoch capture signals from broad regions, making them useful for tracking long-term trends in CO_2, CH_4, and N_2O. Isotopes add key information about the sources, sinks, and processes affecting these gases. Measurements are typically made using isotope ratio mass spectrometry or laser spectroscopy, though both have limitations. Despite challenges such as weak signals and calibration issues, these observations remain valuable, with ongoing improvements needed in time series, calibration, and interpretation.

Timofej Sukhodolov - ***Likely but unpleasant scenarios of the future atmosphere: geoengineering, rockets, and volcanic eruptions***

Not available

Benjamin Stocker - ***Anomaly detection for drought impact monitoring of Swiss forests***

Summer drought is among the top event risks in Switzerland, highlighting the need for spatially explicit monitoring. This presentation combines (i) an overview of our work using Earth Observation (EO) data for drought impact assessment with (ii) a focused case study on vegetation anomaly detection at the national scale.
While existing early-warning systems track precipitation, soil moisture, and hydrology, many impacts are ultimately expressed through vegetation. EO data—especially multispectral and thermal observations—enable consistent monitoring of vegetation dynamics across space and time.
The case study presented here introduces a method to detect anomalies in vegetation greenness by learning the mean seasonal cycle of the normalised difference vegetation index (NDVI) for each location, conditioned on static features and day-of-year. By leveraging information across all pixels, the approach addresses noise and data gaps, producing smoothed time series and quantile-based anomaly estimates. Results demonstrate the detection of drought impacts, reveal patterns across topographic gradients at 30 m spatial resolution, and thus support regional characterization of vegetation stress.
We conclude that EO-derived vegetation greenness anomalies provide a scalable proxy for climate impacts and complement existing drought indicators.

Stephan Henne - ***From atmospheric observations to validation of greenhouse gas emission inventories***

Stephan Henne introduced the concept of inverse modelling of GHG emissions by combining atmospheric composition observations with transport simulations and an optimisation algorithm with a focus on national and sub-national scales (top-down method). Examples were given for observation-based flux estimates that were included in policy relevant documents like the National Inventory Documents (NID) submitted annual to the UNFCCC. These top-down estimates can complement the default bottom-up reporting, based on activity data and emission factors, and may reveal areas of discrepancies. Improved bottom-up reporting of complex sources, such as agricultural emissions from soils, can be compared to top-down emission estimates as well. Examples, where independent emission estimates agree well with each other, include, but are not limited to, N2O fluxes in Switzerland and Germany and Western European HFC trends. Larger differences were found for Swiss and Dutch CH4, Swiss HFC and German SF6 emissions. Reasons for differences are actively discussed between national inventory teams and atmospheric scientists and have triggered policy and public discussion in the mentioned countries. CO2 inversions for the city of Zürich compared relatively well with the city's inventory. For north-western Europe, which has a dense network of ground-based observations, inverse estimates of total non-CO2 GHG fluxes have matured. In contrast, inverse modelling of sector-specific fluxes (e.g., anthropogenic vs. biogenic CO2 or natural gas vs. agriculture CH4) remain challenging but may become more informed thanks to observations of co-emitted tracers (e.g., C2H6, stable isotopes, radiocarbon). The use of satellite observations for inverse modelling poses high precision and accuracy constraints on the observations but promises coverage in otherwise data-sparse regions.

Regula Mülchi - ***How observations support the development of climate scenarios***

The Swiss climate scenarios “Klima CH2025” show that Switzerland is severely affected: more extreme heat, drier summers, heavier precipitation events, and significantly less snow, with every tenth of a degree of warming making a measurable difference. Such climate scenarios are based on projections by climate models. How-

ever, reliable long-term observations are indispensable for developing robust climate scenarios. They play a crucial role in calibrating unresolved physical processes in climate models, tuning the climate models, and evaluating their model performance. Observations also guide model selection by revealing biases in mean states, extremes, and historical temperature trends. High-quality and high-resolution reference datasets are essential for statistical bias correction and downscaling. Finally, the combination of models and observations enables an integrated view of past, present, and future climate and serves as basis for many of the climate scenario products. A wide range of products on different levels of complexity is available under www.climate-scenarios.ch.

Nadine Salzmann - ***The importance of high-mountain cryospheric data for evidence-based decisions – … and how to fill data gaps: Examples from the Swiss Alps and Bhutan***

The currently observed extremely fast changes of the mountain environment and in particular the cryosphere cause (new) process interactions (compound events) and increase the complexity, frequency, and magnitude of risks and hazards, including the risk of events without any precedent ("black swan"). At the example of recent events (e.g. Blatten) it is shown how long-term in-situ observations and earth system data from space (satellites, drones) can critically support the decision makers in taking action, be it in form or early detection (and thus mitigation/adaptation) or in acute situations.
However, in-situ measurements are still rare, often inaccurate and often have major gaps. At the example of a Cosmic Ray Sensor it is presented, how the number of in-situ measurements (here SWE) can be increased in the Swiss Alps and globally, in even more extreme environments such as Bhutan (incl. knowledge transfer) and how to fill spatio-temporal data gaps by using AI/ML.
The talk concludes with important messages regarding the challenges of sustainable long-term in-situ measurements. It is getting increasingly challenging collecting data and maintaining observation sites due to the rapid warming. Site maintenance becomes more dangerous, demanding and also costly. In addition, current sites at too low elevation will be lost because there are no permafrost and glaciers anymore. This requires adjusting the long-term networks.
Despite the huge efforts needed to maintain long-term *in situ* measurements, these measurements are indispensable key for any use of satellite data (ground truth) or AI/ML approaches. These techniques do not replace any in-situ measurements, rather they fully build and depend on them.

Fabia Hüsler - ***From Data to Decision Support: The Swiss Drought Early Warning and Monitoring System***

Having recognized drought as a relevant risk for various economic sectors in Switzerland, in 2022 the Federal Council mandated the responsible government agencies to establish a comprehensive national monitoring and early-warning system. The aim is to facilitate proactive drought management by providing users with timely and accurate information for informed decision making. The recently launched system synthesizes various data streams (i.e. precipitation, streamflow and groundwater, space-based monitoring of vegetation) and provides 4-week forecasts of drought quantities. Historical observations and sub-seasonal forecasts are merged to provide seamless information on drought that can easily and interactively be compared to action-relevant thresholds as well as historical events. The main drought variables are summarized into a combined drought index which is used to provide an overall evaluation of the situation and forms the basis for coordinated action and national drought warnings. The drought warnings are issued by national agencies through official channels and are designed to anticipate severe drought periods thereby increasing the scope for action for local authorities. Overall, the drought early-warning system showcases a good example of how interdisciplinary collaboration and the integration and combination of diverse Earth observation data creates an impactful decision support tool.

C List of Posters

Table 1: List of Posters

Poster	Author(s)	Institution(s)
Increasing Importance of Earth System Data		
Accurate in-situ monitoring of UTLS water vapor by laser absorption spectroscopy	S. Brunamonti B. Tuzson Swiss H_2O-Hub	Empa
URS – an open access platform for standardized Swiss urban climate data	M. Burger P. Bigler M. Gubler S. Brönnimann	University of Bern
A cryogenically cooled radiometer, for middle atmospheric water vapor retrievals	A. Filinis A. Bell A. Murk G. Stober Swiss H_2O-Hub	University of Bern
Assessment of summer drying in Switzerland – with focus on observational soil moisture and runoff data	M. Hirschi L. Gudmundsson B. Kraft S. Seneviratne	ETH Zurich
Renewal of the FTIR platform at Jungfraujoch: first characterization of the performance of the new equipment	E. Mahieu	University of Liège
Swiss H_2O Hub observations of post Hunga-Tonga UTLS water vapor with balloon-borne frost point hygrometers	Y. Poltera[1] F. Wienhold[2] V. Artho[2] S. Brossi[3] T. Brossi[3] S. Brunamonti[4] G. Romanens[5] A. Brun[2] B. Luo[2] T. Peter[2] G. Stober[1]	[1]University of Bern [2]ETH Zurich [3]mylab elektronik GmbH, Bubikon [4]Empa [5]MeteoSwiss
Automatization of the totalizer network in Switzerland: results of the pilot phase	M. Rohrer[1] M. Schwarb[1] D. Lorenzi[1] C. Allemann[2] C. Hotz[2] T. Konzelmann[2] S. Vogt[2] C. Marty[3]	[1]Meteodat GmbH [2]MeteoSwiss [3]WSL/SLF
Standardizing atmospheric measurements of halogenated VOCs based on SI-traceability	D. Roos T. Bühlmann M. K. Vollmer F. Hiault E. Mahieu S. Reimann	Metas Empa University of Liège
GAW QC – an interactive dashboard to facilitate quality control of *in situ* atmospheric composition measurements	M. Steinbacher Y. Brugnara S. Baffelli C. Zellweger L. Emmenegger	Empa

The Quality Assurance / Science Activity Centre Switzerland of WMO's Global Atmosphere Watch Programme	M. Steinbacher C. Zellweger Y. Brugnara L. Emmenegger	Empa
Development and Application of the Peltier Cooled Frostpoint Hygrometer (PCFH) for Water Vapor Measurements up to the Lower Stratosphere	F. Wienhold[1] S. Brossi[2] T. Brossi[2] Y. Poltera[3] T. Peter[1]	[1]ETH Zurich [2]mylab elektronik GmbH, Bubikon [3]University of Bern
Three Decades of WCC-Empa Audits: Strengthening Traceability and Data Quality in the GAW Network	C. Zellweger M. Steinbacher L. Emmenegger	Empa
Towards Stand-Alone Monitoring of Carbonaceous Aerosol: FATCAT Measurements and Thermogram-Based Interpretation	A. Keller	FHNW
GCOS Switzerland – Inventory Report, Update 2025	Swiss GAW/GCOS Office	MeteoSwiss
GAW-CH and GCOS-CH supported activities – Monitoring	Swiss GAW/GCOS Office	MeteoSwiss
GAW-CH and GCOS-CH supported activities – Central Facilities	Swiss GAW/GCOS Office	MeteoSwiss

Earth System Data for Impactful Applications

From Dust to Wildfire Smoke: Influence of Extreme Events on Aerosol Properties on Jungfraujoch	B. Brem[1] L. Simon[1] R.L. Modini[1] M. Collaud[2] C. Mohr[1] M. Gysel-Beer[1]	[1]PSI [2]MeteoSwiss
ICOS Switzerland: The Swiss Contribution to a Pan-European Environmental Research Infrastructure	S. Burri[1] N. Buchmann[1] F. Conen[2] L. Emmenegger[3] A. Haefele[4] E. Harris[5] M. Kalberer[2] R. Zweifel[6]	[1]ETH Zurich [2]University of Basel [3]Empa [4]MeteoSwiss [5]University of Bern [6]WSL
A 3D radiation model for urban ecophysiology modelling	G. Cavalcabo' S. Stagakis M. Kalberer	University of Basel
Detection and 24-year climatology of the frequency and mass of Saharan dust at the high-altitude site Jungfraujoch	M. Collaud[1] B.T. Brem[2] R. Modini[2] M. Gysel-Beer[2] M. Steinbacher[3] S. Henne[3]	[1]MeteoSwiss [2]PSI [3]Empa
High-resolution seasonal soil moisture maps for Swiss forests	A. Dietzel F. Zellweger K. Meusburger	WSL
Overall uncertainty budget of Dobsons from the Arosa/Davos total column ozone timeseries.	L. Egli[1] J. Gröbner[1] R. Rüfenacht[2] F. Cabello[1] V. Velaszco[3] G. Porrovecchio[4] M. Smid[4]	[1]PMOD/WRC [2]MeteoSwiss [3]DWD [4]CMI
Detecting drought impacts on ecosystem physiology from multispectral, thermal, and meteorological remote sensing data.	Y. El-Mejjaouy	University of Bern

Where do city trees get their water? Urban density effects on tree water uptake in Zurich	S. Emberger[1] L. Scapucci[1] S. Stagakis[2] N. Buchmann[1]	[1]ETH Zurich [2]University of Basel
Automatic and real-time Swiss pollen monitoring network	S. Erb	MeteoSwiss
A physically based approach to compensate for shadow effects in imaging spectroscopy data	L. Groeneveld A. Damm	University of Zurich
Permafrost evolution in the Swiss Alps based on 25 years of coordinated observation	J. Noetzli C. Pellet	SLF
GNSS-IR for snow and soil moisture retrieval	B. Soja	ETH Zurich

D List of Participants

Table 2: List of Participants

Participants		Institution
Speakers		
Antonio	Bombelli	WMO
Michael	Brechbühler	Eawag
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Dominik	Brunner	Empa
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[3]Eliza	Harris	University of Bern
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Laurence	Rouil	ECMWF
Nadine	Salzmann	SLF/WSL
Felix	Seidel	GeoLab
Stavros	Stagakis	University of Basel
Gunter	Stober	University of Bern
Benjamin	Stocker	University of Bern
Timofei	Sukhodolov	PMOD/WRC
Jan Dirk	Wegner	University of Zürich
Petra	Zimmermann	MeteoSwiss
High-Level Panel		
Martin	Ackermann	Eawag
Stefan	Brönnimann	University of Bern
Brigitte	Buchmann	SSC GAW-CH/GCOS-CH
Thomas	Frölicher	University of Bern (excused)

1 On behalf of Martin Hoelzle, University of Fribourg

2 Remote

3 Prerecorded

Ulrike	Lohmann	ETH Zürich, IAC
Laurence	Rouil	ECMWF
Felix	Seidel	GeoLab
Stefan	Uhlenbrook	MeteoSwiss

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Andrea	Rossa	MeteoSwiss
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Martin	Gysel-Beer	Paul Scherrer Institute
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