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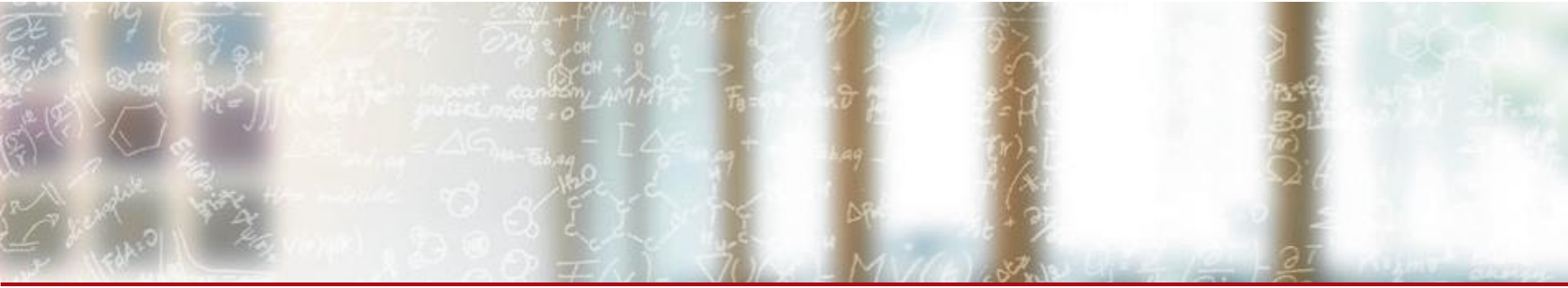
Centro Svizzero di Calcolo Scientifico
Swiss National Supercomputing Centre

Bundesamt für Meteorologie und
Klimatologie MeteoSchweiz

ETH zürich



Redefining Weather Forecasting Systems: The Transition to ICON and Alps

Cray User Group, CUG 2025

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Swiss Federal Office for Meteorology and Climatology (MeteoSwiss)

Mission
MeteoSwiss is the national weather and climate service with the mandate to protect the population, infrastructure, and environment in Switzerland.

MeteoSwiss operates the national surface and radar measurement network, collects, manages, and analyses weather and climate data. **MeteoSwiss produces forecasts and issues information, warnings, and advices.**

Swiss National Supercomputing Center (CSCS)

Mission
CSCS develops and operates a High-Performance Computing and data research infrastructure that supports world-class science in Switzerland.

CSCS is making available computing resources to domestic and international researchers via the user lab. Furthermore, resources are opened to contractual partners.

The ICON-22 project
Key services of MeteoSwiss

Production services

- The operational weather forecasting service of MeteoSwiss
  - MeteoSwiss is required to be operational continuously, 24 hours a day, 7 days a week, 365 days a year.
  - Primary objectives of this service are:
    - **High-availability**
    - **Service resiliency/continuity**
    - **Fail-over capabilities**
- Research and development services to advance forecasting capabilities.

Additional activities

- MeteoSwiss collaborates on larger research topics, such as climate change, with research institutes in Switzerland and internationally.

The ICON-22 project
Setting the expectations

MeteoSwiss

- Deploy ICON in the operational forecasting business of MeteoSwiss.
- The new models, ICON-CH1-EPS and ICON-CH2-EPS surpass (or at least equal) the existing models in terms of quality.

CSCS

- Transition of MeteoSwiss as a tenant onto the Alps infrastructure.
- Investigate and implement new features and technologies around the use case of MeteoSwiss.

Stability and continuity

Continuous development of Alps

Historically, the difference in the speed of adapting new technologies was achieved by:

- Operating on isolated, dedicated HPC environments (clusters or partitions of a cluster)
- Statically configured setups
  - Facilitates operating the systems due to reduced complexity.
  - Limiting elasticity and continuity of the R&D services in case of fail-over scenarios.

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History of MeteoSwiss systems at CSCS

2007

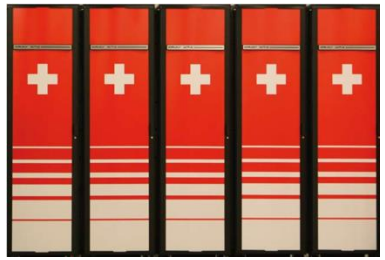
2012

2016

2020

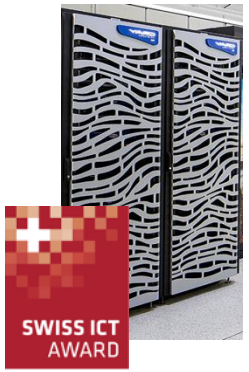
2024

CPU based architecture with dedicated asymmetric systems



Dole – Buin
Cray XT4

Lema – Albis
Cray XE6



Kesh
Escha

Cray
CS-Storm

Transition from CPU to GPU Dedicated symmetric systems **Swiss ICT Award**

Arolla
Tsa

Cray
CS-Storm

GPU based dedicated asymmetric systems with node repurpose feature

Alps
HPE Cray EX

Alps vCluster technology on multiple zones with elasticity feature

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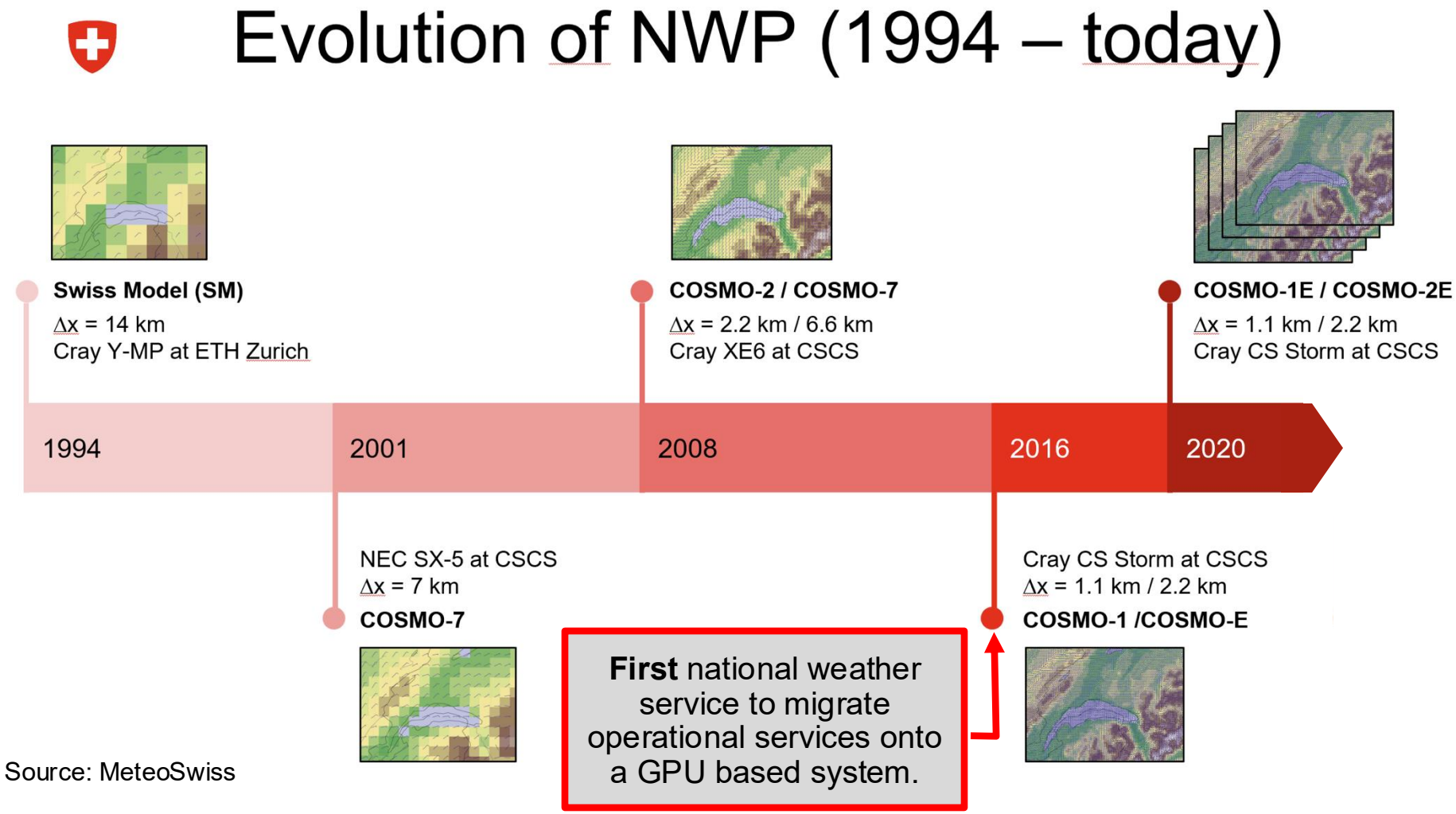
Evolution of operational weather forecast



Source: MeteoSwiss

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New Infrastructure, New Model

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New Infrastructure, New Model
Short recap of the main Alps features

- Alps infrastructure
  - Designed for programmability of resources (Infrastructure as Code).
  - Designed for multitenancy
    - Allowing classical HPC next to AI/ML and data-driven workflows on the same infrastructure.
  - Enabling multi-zone configuration
    - Alps on-site at CSCS, Lugano.
    - AlpsE at EPFL, Lausanne.
    - AlpsB at ECMWF, Bologna.
- Versatile software-defined clusters (vClusters)
  - Collection of resources and vServices into a supercomputing ecosystem.
  - Manage platform services and provisioning of clusters.
- Versatile cluster microservice (vService)
  - Small, independent, and loosely-coupled services hosted on a vCluster.
  - Managed by a second control plane.
  - Allowing for independent technology stacks on different vClusters.

Selection of CUG contributions describing Alps in more detail:

- Deploying Cloud-Native HPC Clusters on HPE Cray EX, F. Cruz et al., CUG 2023
- Multitenancy on HPE Cray EX: network segmentation and isolation, C. Gamboni, CUG 2024
- Alps, a versatile research infrastructure, M. Martinasso et al., CUG 2025

New Infrastructure, New Model
The ICON model

- **ICO**sahedral **N**onhydrostatic (ICON) modelling framework
- Originally developed by the German Weather Service (DWD) and the Max Planck Institute for Meteorolgy (MPI-M)
- International Collaborations
  - The ICON partnership is overseeing development and continuous improvement of the ICON model.
  - The Consortium for Small-scale Modelling (COSMO) is dedicated to advancing and improving non-hydrostatic regional weather models and decided to replace the COSMO model with the ICON model.
  - MeteoSwiss is actively involved in both, the ICON partnership and the COSMO consortium.

New Infrastructure, New Model
Advantages of ICON over COSMO

Triangular (icosahedral) elements

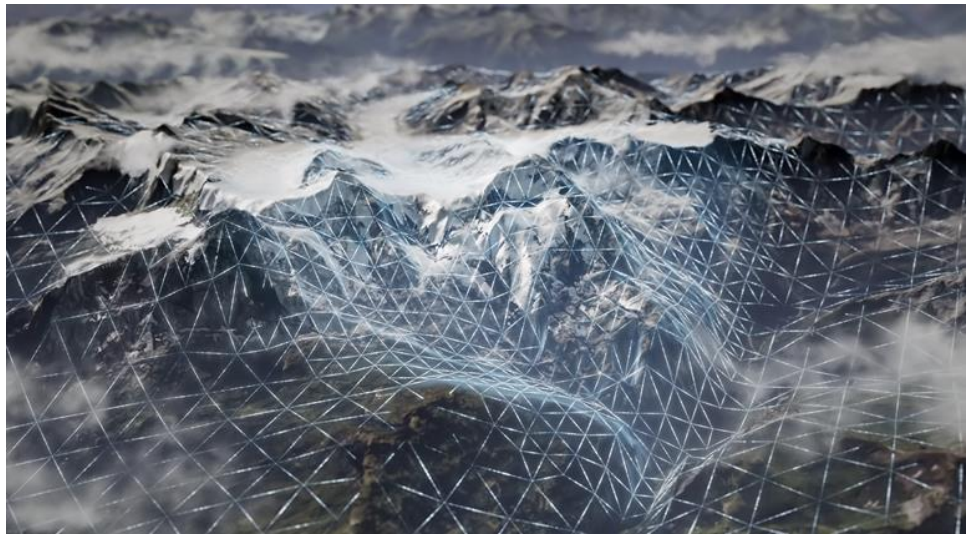
- Enabling a significantly more homogeneous element size distribution across the grid, particularly at the Earth's poles.
- Capturing more accurately the intricate details of the complex Alpine topography.

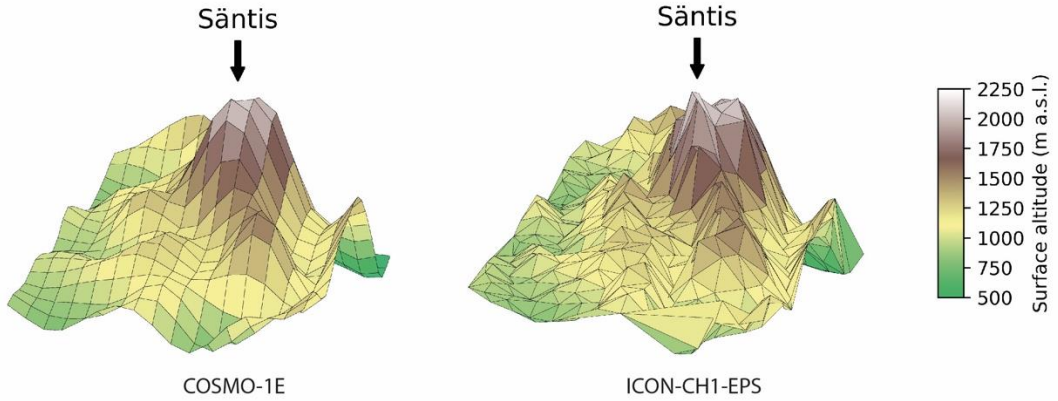
Improvement of the numerical methods

- New formulation of the flow equations is adapted to capture steeper mountain slopes.

Targeted resource usage

- Calculate individual areas of interest with a higher spatial resolution.





Source: MeteoSwiss

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New Infrastructure, New Model

What this means for MeteoSwiss

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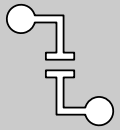
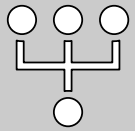
What this means for MeteoSwiss
Benefits by using vCluster(s) and vServices



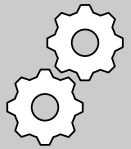
Isolated Execution on Shared Infrastructure

vClusters offer stringent namespace and resource separation, facilitating MeteoSwiss's predictable operation within a multi-tenant environment. This isolation ensures that MeteoSwiss's operations are not adversely affected by other platforms.



Dynamic Resource Allocation

On-demand access to resources across the broader Alps infrastructure enables MeteoSwiss to scale compute resources beyond the fixed capacity of its previous system. This elasticity is particularly advantageous during forecast-critical events or during parallel development and validation phases.



Enhanced Test and Validation Capabilities

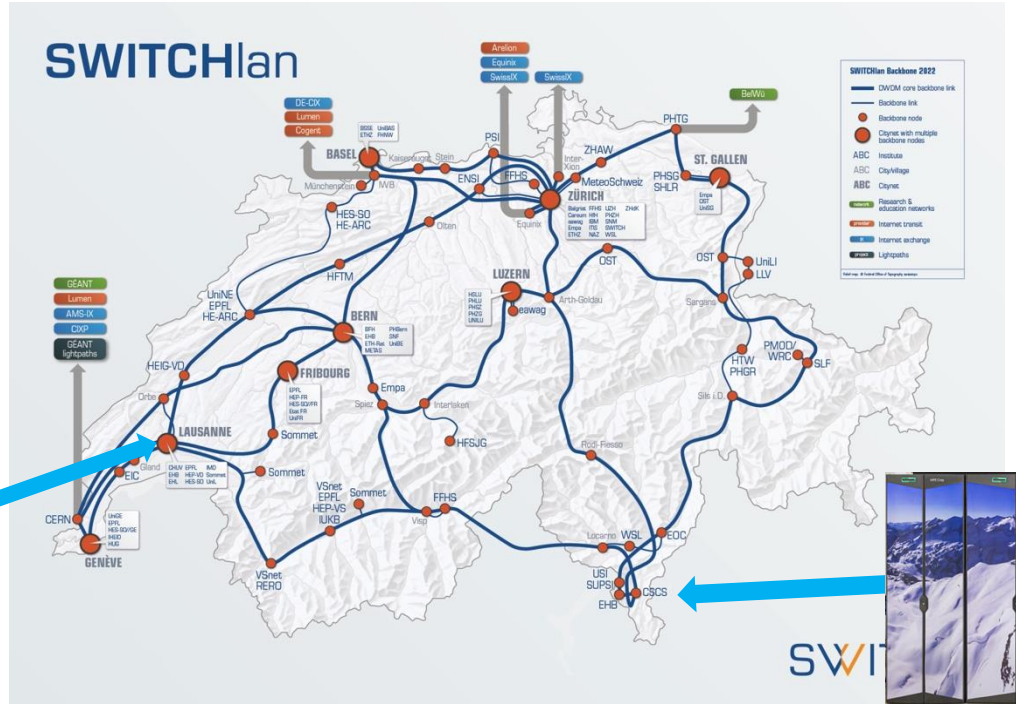
In the future, the support for deploying test vClusters will further enhance staging and pre-production testing workflows.

This is supported by the utilization of User Environment (UENVs), which has streamlined environment management and facilitated reproducibility. These environments can be versioned and deployed concurrently with production systems, thereby simplifying the validation of model updates or system modifications.

What this means for MeteoSwiss
Benefits due to the multizonal setup of Alps

Simplified fail-over and resiliency

The alignment of the two vClusters hosting the operational and R&D services across geographically distinct facilities – currently at CSCS and EPFL – enables rapid role switching during planned maintenance or failure scenarios, improving service continuity with minimal configuration changes.



The ICON-22 project

New Infrastructure, New Model

What this means for MeteoSwiss

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Looking back
Some hick-ups along the journey

Planning is always tricky

- Official project start in October 2019 with an intended duration of 2 years.
- Ambitious project migrating to an entirely new setup (infrastructure, workflows, key application)
- Beginning 2020 reality happened and turned everything upside down.
  - Deliveries delayed due to disrupted supply chains.
  - Timelines got shifted (and also compressed)
  - Ambitious planning leads to developments suddenly happening simultaneously
    - Features needed were not available or fully developed.
- Major project activities started in 2022.

Looking back
Some hick-ups along the journey

Increase in complexity of the new setup

- Initial plan was to use full vCluster configuration including vServices
- vServices and corresponding control plane
  - Fail-over readiness and coverage by on-call service of the setup was not ready in time.
  - Leading to an interim solution currently still used:
    - Exception to the normal workflows on Alps, e.g.:
      - SLURM service still installed on the management plane instead of an orchestrator deployment.
      - UENV is available, operational environment permanently mounted instead of using the UENV tooling.
    - **Always problematic** for operating production services since Manual intervention are necessary!

Application performance

- Estimate vs. real-world performance
  - Additional time needed to optimize the workflow to the new setup.
  - Real-time evaluation of workflow performance on the new system, e.g.:
    - Switching from GPFS to Lustre has some implications on workflow related performance.

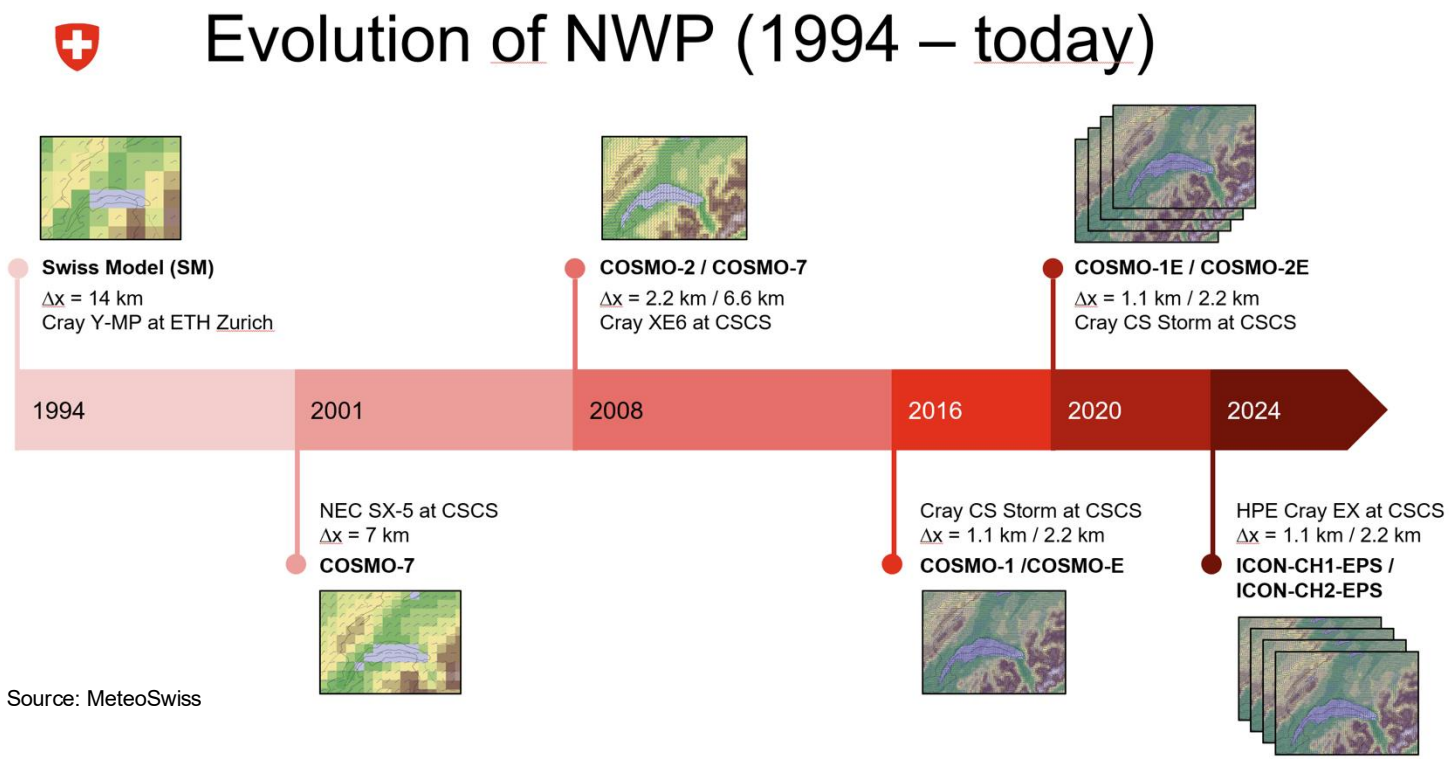
Looking back
Some hick-ups along the journey

Testing coverage needed to be built

- Testing for configurations/deployments being created while going forward.
- Example:
  - Capability to access EPFL network directly is available and was tested.
  - Initial configuration at ISP still routed traffic through CSCS
    - This was realized during a power outage at CSCS, which affected network connectivity.
    - The situation returned to normal quickly once the base services of CSCS were resumed.
    - Configuration was adjusted after a change request with the ISP to correct for this.
  - Looking at the bright side:
    - During the incident, automatic workflows of MeteoSwiss continued running.
    - **Confirmation** of fail-over concept, despite not being fully geo-redundant.

Looking back

It's not yet perfect, but…



…MeteoSwiss operational weather forecasting and R&D services are **running on the Alps infrastructure since September 2024**!

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New Infrastructure, New Model

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Future work

ICON-22 related

- Fully geo-redundant configuration
  - Current geo-distributed setup already showed the potential of the concept.
  - Need to further make the setup at EPFL self-sufficient.
  - Additional resources for ancillary services are already installed at EPFL.
  - Current activities identifying next service to be replicated (LDAP, DNS, …)
- vCluster configuration
  - Move towards a setup using the vServices managed with the NOMAD control plane
  - Increase fraction of automated workflows for vCluster/vService management.
  - Reach capability to allow other workloads next to MeteoSwiss on the EPFL system.

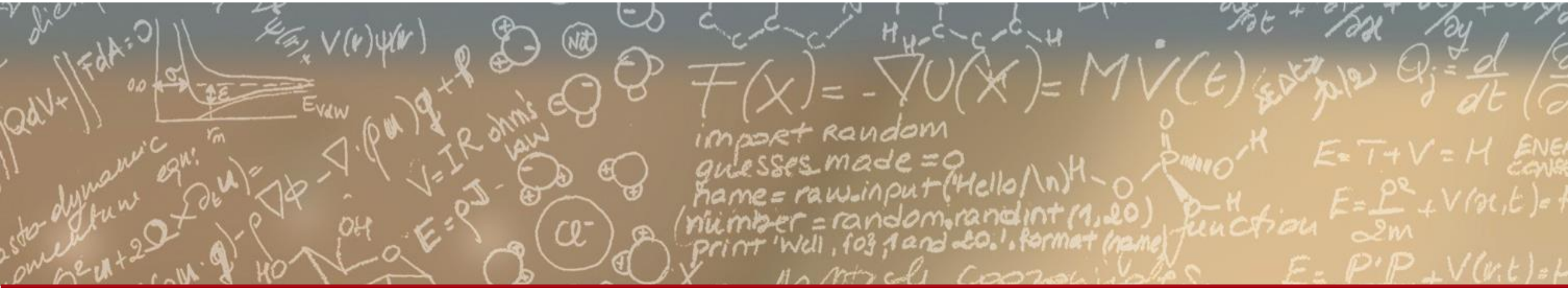
Long-term developments

- MeteoSwiss service mobility/resilience
  - Intention to enhance fail-over capability.
- EXCLAIM
  - Project aims at developing an **EX**treme scale **C**omputing and data platform for c**L**oud-resolving we**A**ther and cl**I**mate **M**odeling
  - ICON-model based infrastructure capable of **running kilometer-scale climate simulations at both regional and global scales**.

Dedication

Dedication

We dedicate this presentation to **André Walser** from MeteoSwiss, whose unwavering support and deep insight were instrumental in making the implementation presented today possible. Though he has passed away, the foundation he helped establish will continue to shape future developments for many years to come.



Thank you for your attention.