# FROM ZERO TO OPERATIONAL: RAPID DEPLOYMENT OF SNOW COVER SIMULATIONS VIA THE OPEN SOURCE FRAMEWORK AWSOME INTERNATIONAL SNOW SCIENCE WORKSHOP 2026, WHISTLER, CANADA

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ABSTRACT: The *Avalanche Warning Service Operational Meteo Environment* (AWSOME) is an open-source framework for seasonal snow-cover modeling in both research and operational avalanche warning. It addresses the recurring technical effort required to connect meteorological data, snow models, post-processing, visualization, and deployment into reproducible workflows.

AWSOME provides modular tools for acquiring and harmonizing forcing data, running distributed snowpack simulations, initializing models from observations, deriving instability information, and visualizing results. Workflows can range from small standalone experiments to continuously running operational model chains, while sharing the same interfaces and data structures. Open data sources allow workflows to be transferred between regions with little additional setup.

The framework is designed to keep technical complexity inside the system rather than passing it on to the user. In this way, AWSOME aims to lower the barrier to state-of-the-art snow-cover modeling, make research workflows easier to reproduce and operationalize, and provide a common foundation for collaborative development across the snow and avalanche community.

KEYWORDS: modeling, forecasting, snowpack, AWSOME

## 1. INTRODUCTION

Detailed snow-cover models such as SNOWPACK (Bartelt and Lehning 2002; Lehning et al. 2002) and Crocus (Vionnet et al. 2012) have become an established part of operational avalanche forecasting (Morin et al. 2020). Distributed simulations have been validated at large scale against observed critical layers (Herla et al. 2024a) and are increasingly used to derive quantitative avalanche hazard information (Herla et al. 2025a). Turning these models into robust research or operational workflows, however, still requires substantial technical integration.

Much of this effort is repeated across projects: acquiring and harmonizing forcing data, configuring models, managing initialization and state, post-processing results, and connecting outputs to visualization or operational systems. This not only raises the barrier to getting started, but also makes workflows harder to reproduce, transfer between institutions, and maintain over time.

AWSOME is an open-source framework for snow-cover modeling that aims to move this recurring integration work into shared and reusable components. It collects and adapts tools developed across the scientific community and connects them through common workflows and data structures (Herla et al. 2024b). Developed in the context of operational warning services (Herla et al. 2024c), AWSOME is intended to support the same underlying tools from focused research experiments (Reisecker and Mitterer 2024) to continuously running operational applications and use by winter professionals in the field (Reisecker and Krieger 2026).

## 2. TECHNICAL VISION

AWSOME is intended to feel like an “operating system for snow-cover modeling”: the complexity of the underlying toolchain should remain inside the framework rather than being passed on to the user. The aim is that common workflows can be started with minimal configuration, while still remaining portable, reproducible, and flexible enough for both research and operations.

A few design principles follow from this idea. Features should work without mandatory additional setup wherever possible, complex workflows should be controllable through concise high-level calls, and open data alternatives should be available whenever practical. Domain definitions and workflows should also remain transferable

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between regions instead of depending on site-specific assumptions.

```
# install the snow-cover and visualization stack
installer/install.sh --mod_snowpack --mod_visualization
```

This lowers the barrier to getting started, but just as importantly it makes workflows easier to move between development, production, and cluster environments. New ideas can be explored in a lightweight setting and later promoted into operational use without rebuilding the modeling chain from scratch.

For example, a user interested in a new region can define an area, distribute simulation points across it, and perform a seasonal reanalysis to obtain a first overview. Data sources or snow models can then be exchanged without changing the overall workflow. The same principle applies in operations, where limited time often makes model exploration difficult: the framework is intended to reduce the task to specifying the area or points of interest and launching an established workflow.

## 3. TECHNICAL IMPLEMENTATION

AWSOME combines modular snow-cover modeling packages with an installer that prepares the surrounding software environment. The aim is to make complete modeling workflows reproducible while still allowing individual components to be used independently.

Installations can range from a small set of packages for a focused research task to a complete system for operational simulations. This modular structure allows individual components to evolve separately while remaining interoperable through shared interfaces and data structures.

AWSOME is developed primarily for GNU/Linux, where the full modeling environment can be deployed directly. Most core packages are themselves platform-independent, while containers provide an additional way to reproduce the same environment on clusters, temporary systems, or other operating systems (Section 4.3.).

A central element connecting these components is xsnow, a community-driven data format and Python package for snow-cover modeling (Herla et al. 2025b). By using a common data structure across models, data sources, post-processing, and visualization, AWSOME can combine otherwise independent tools into the same workflow without requiring each connection to be implemented separately.

## 4. MODES OF OPERATING AWSOME

AWSOME is designed to support different levels of commitment, from using a single package for a focused experiment to running a complete operational modeling system. The underlying tools and data structures remain the same, so workflows can grow in complexity without having to be rebuilt from scratch.

### *4.1. Standalone research usage*

Individual AWSOME packages can be used independently for targeted research questions. For example, Open-Meteo data and the SNOWPACK engine ProfSnow can be combined to run historical or forecasting SNOWPACK simulations without deploying the full framework. This makes it possible to use AWSOME selectively where only a small part of the toolchain is needed.

### *4.2. On an AWSOME machine*

An “AWSOME machine” is a system where most or all of the framework has been deployed and common software, data, and conventions are already in place. This reduces repetitive setup and allows more complex workflows to remain concise and reproducible. Different snow models such as SNOWPACK, FSM2, and SNOWGRID can be compared within the same environment without separately managing the infrastructure each of them requires, and the results can be explored straight away in nivix (Section 5.5.) or the dashboard (Section 5.6.), which run as part of the machine.

### *4.3. Containerized simulations*

Containers provide a portable way to run the same workflows in isolated or otherwise different computing environments. AWSOME supports Docker and Apptainer, allowing simulations to be transferred to clusters, temporary systems, or operating systems where a native installation would be impractical.

Because a container carries its own environment, it can provide a complete AWSOME machine on a personal computer independent of its operating system: the simulation runs inside the container while the dashboard is exposed on a local port and used in the browser exactly as it would be on an installed system. On a server, the same isolation allows several versions of an operational setup to run side by side, so development versions can be tested in parallel against the one currently in production and promoted once they prove reliable.

Together, these modes allow the same ideas to move from a small standalone experiment to a

repeatable research workflow and, eventually, to an operational deployment.

# 5. CORE PACKAGES OF AWSOME

## *5.1. The SNOWPACK engine ProfSnow*

ProfSnow provides a high-level interface to SNOWPACK (Bartelt and Lehning 2002; Lehning et al. 2002) for both research and operational applications, complementing established configuration tooling for the SNOWPACK/MeteoIO stack (Bavay et al. 2022). It abstracts much of the configuration and state-file handling that would otherwise need to be managed manually while retaining support for different forcing and initialization strategies.

Simulations can be driven by automatic weather stations or numerical weather prediction output (Bellaire et al. 2011), and initialized from observed snow profiles (Binder and Mitterer 2023; Binder et al. 2024). The same interface can therefore be used for one-off experiments and continuously updated operational runs.

## *5.2. AWSOME's data hub ADataHub*

ADataHub provides a common interface between external data sources and snow-cover modeling workflows. Its main purpose is to hide the differences between individual data providers and transform their output into consistent, SNOWPACK-ready xsnow datasets.

Meteorological and spatial data can originate from local files, remote services, gridded products, point observations, or other AWSOME data-source plugins. Regardless of their origin, the same mechanisms can be used to define a modeling domain, extract point or grid data, and combine several sources. Larger datasets can be downloaded in parallel and processed in chunks where necessary, without changing the surrounding workflow. This allows, for example, one dataset to provide the primary forcing while another fills gaps or extends its temporal coverage.

By separating the modeling workflow from the details of data access, ADataHub makes it possible to exchange data sources without redesigning the surrounding toolchain. This is particularly important for AWSOME's goal of making the same workflows portable between research experiments, operational systems, and different geographic regions.

## *5.3. AWSOME's master toolchain AToolchain*

AToolchain connects AWSOME's individual components into complete modeling workflows. Rather than requiring users to write custom scripts, simulations are described through human-readable "recipes" that define the domain, data sources, models, processing steps, and outputs.

This declarative approach makes complex workflows easier to reproduce, modify, and transfer between environments. New capabilities implemented in the underlying packages can often be exposed directly through the recipe, allowing research ideas to be tested and later promoted into operational workflows with little restructuring.

A recipe can describe an entire distributed snow-cover simulation (Section 8.), while AToolchain handles the technical orchestration in the background, including parallel execution, memory budgeting, logging, safe data updates, and general housekeeping. The same recipe is executed through a concise call to AWSOME's API:

```
aw run /path/to/recipe.yaml
```

In this way, the recipe describes what should be simulated, while the framework manages how the individual components are connected and executed.

## *5.4. The instability index package snowstab*

Snowstab collects AWSOME's post-processing methods for translating simulated snow stratigraphy into indicators that are more directly useful for stability assessment. These include profile aggregation (Herla et al. 2021; Herla et al. 2022) and probabilistic instability estimates such as `P_unstable` (Mayer et al. 2022).

Beyond individual simulation points, these results can be combined into regional summaries of snow stability and avalanche problems (Herla et al. 2024b; Herla et al. 2025a). In this way, snowstab provides a bridge between detailed physical snow-cover simulations and the spatially aggregated information used in avalanche hazard assessment. A standardized assignment of avalanche problems is an important prerequisite for this step (Walcher and Lanzanasto 2023a).

## *5.5. The visualization tool nivix*

nivix is AWSOME's interactive visualization environment for exploring multidimensional snow-cover model output. It is designed around xsnow datasets and allows users to move between de-

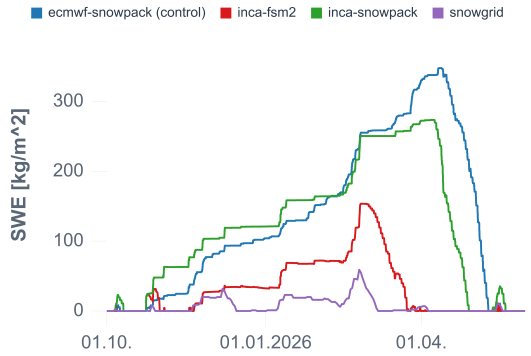



Figure 1: Comparison of multiple realizations in nivix. Snow water equivalent (SWE) is shown at a single location for simulations using different physical models and meteorological forcing datasets. Because realizations are represented directly in the xsnow data structure, they integrate natively.

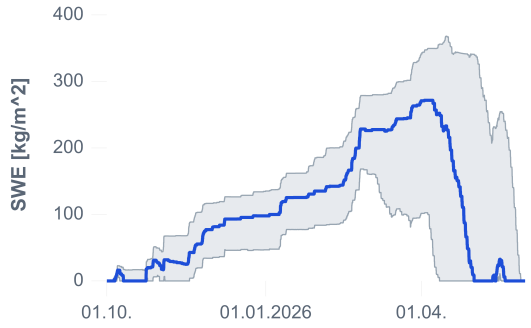



Figure 2: Ensemble view of the same SWE dataset across all locations and realizations. nivix combines the selected dimensions and summarizes their distribution while responding to the current spatial filters, allowing large distributed datasets to be reduced to an overview without discarding the underlying members.

tailed stratigraphy, temporal evolution, ensemble spread, profile views, and derived stability information.

This is particularly useful for distributed and ensemble simulations, where the challenge is not only producing large amounts of model output but also navigating it efficiently. nivix therefore combines overview and detail: users can explore dimensions, realizations, and spatial or temporal subsets interactively while retaining access to the underlying snow stratigraphy and model parameters.

A backend prepares the requested subsets from potentially large datasets, while the browser-based frontend handles the interactive visualization. Additional views such as clustering and EAWS matrix

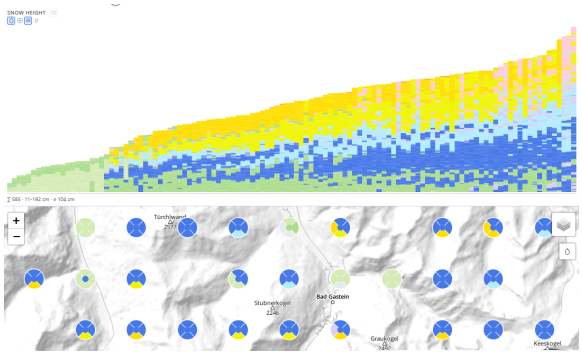


Figure 3: Overview-to-detail exploration in the AWSOME dashboard. The map is shown alongside an ensemble view in which simulation points are sorted by snow height and colored by their modeled stratigraphy (top), while the grain type of the weakest layer is summarized by aspect (bottom). The overview reveals spatial patterns at a glance: several low-snow valley profiles are approaching isothermal conditions at $0\,^{\circ}$C, south-facing slopes are dominated by new-snow instabilities, while depth hoar prevails in the weakest layers on northern slopes.

representations support more targeted exploration for research and operational assessment.

### *5.6. AWSOME's dashboard ADashboard*

The AWSOME dashboard serves two audiences at once: forecasters, by bringing snow-cover model output into their daily workflow, and researchers, by giving them an intuitive yet powerful tool for exploring their own datasets. It is a spin-off of the EUREGIO-ALBINA dashboard (Lanzanasto et al. 2018; Mitterer et al. 2018), whose administrative interface is already in operational use at European warning services for bulletin production (ALBINA Consortium 2026). That dashboard collects and displays observations related to snowpack stability, from simple avalanche sightings to detailed snow profiles drawn from regional networks such as LAWIS (Kriz et al. 2018).

Rather than introducing a separate modeling interface, AWSOME embeds simulated information into this familiar environment, allowing forecasters to consider model results alongside observations and other inputs used in the daily assessment (Walcher and Lanzanasto 2023b). Composable filters, a map that interacts with a hazard chart and time series, and linked detail views allow users to move from a regional overview (Fig. 4) to detailed information for individual locations (Fig. 5).

The dashboard is deliberately data-driven: its input

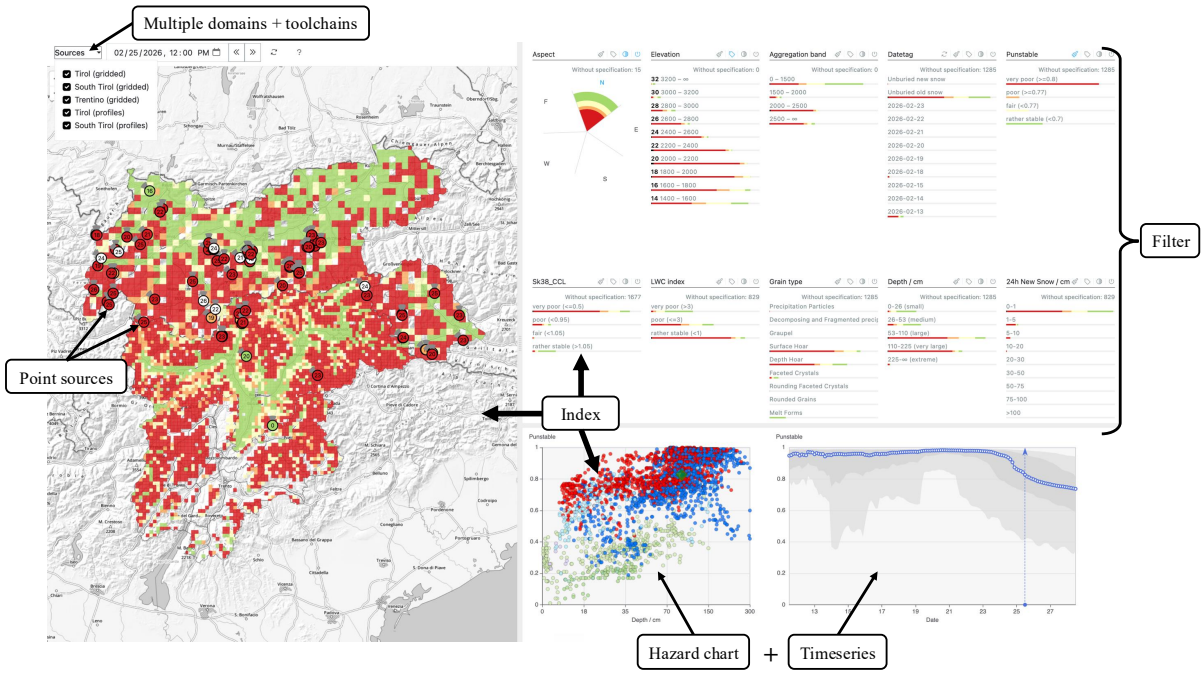



Figure 4: The AWSOME dashboard, showing an example operational setup for the EUREGIO forecasting region. The source menu (top left) lists the available domains and model chains. Choosing filters (top right), or picking one or more regions on the map, immediately updates the hazard chart and time series (bottom right) with it, so every panel constantly reflects the same selection.

carries not only the values to be displayed, but also a description of how they should be visualized and filtered. The same interface can therefore serve different model products, operational needs, or an entirely experimental dataset without redesigning the dashboard itself.

In practice, a single instance can serve several domains fed by fundamentally different toolchains, so that regional products and local high-resolution setups sit side by side. Because every view is bound to the same selection, choosing a filter or picking regions on the map updates the hazard chart and the time series with it (Fig. 4). A forecaster can isolate a single situation of interest that way, and because the filters compose freely, a researcher can chase whichever thread the data suggests.

## 6. ACCOMPANYING PACKAGES

AWSOME is conceptually model-agnostic and extends beyond the capabilities of any single snow-cover model. SNOWPACK remains the best-integrated model, while additional packages broaden the framework where other models, data sources, or physical processes are needed.

These extensions include WRF for generating meteorological forcing that may not be available from public numerical weather prediction products, FSM2 as an independent snow model using the same downstream data structures, and AwaFrame and avapra for avalanche release and dynamics. The SMP-chain links SnowMicroPenetrometer measurements to visualization and fracture-mechanics analyses (Reisecker and Mitterer 2024).

Other packages provide the spatial and environmental context for distributed simulations. TerraGrids supplies elevation, forest-cover, and land-use data, while Tesselation generates terrain-aware points of interest that can represent an area with fewer, more targeted simulation points. Additional modules support meteorological interpolation, satellite data, terrain shading, and parameterizations for missing forcing variables.

Together, these packages allow AWSOME to grow from a snowpack model runner into a broader research and operational environment while retaining common workflows and data structures across applications.

## 7. RESEARCH EXAMPLE

Incoming longwave radiation (ILWR) is an essential forcing variable for snow-cover models, but is not provided directly by many publicly available

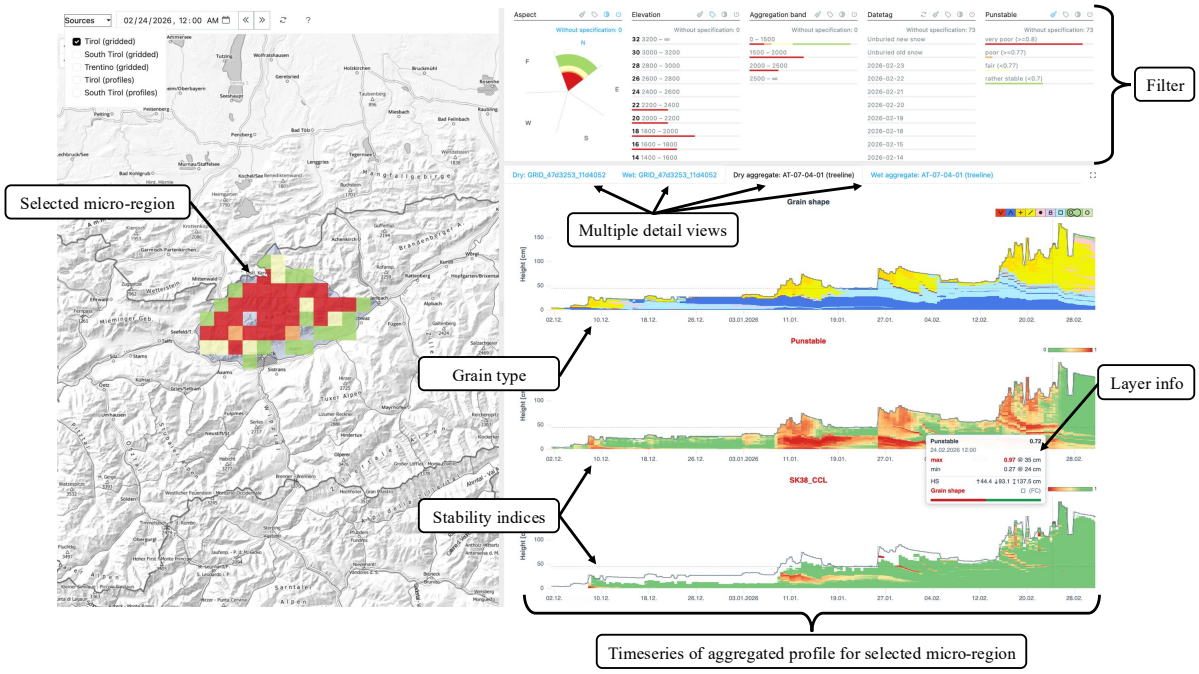



Figure 5: The AWSOME dashboard with a nivix detail view for dry-snow instability. Three time series (grain type, `P_unstable` and `SK38_CCL`) are stacked for the aggregated snowpack of a single micro-region (Karwendel, selected on the map) and a single aspect (north, selected in the filter panel), so that stratigraphy and instability indices can be read against each other over the season.

meteorological products. It is therefore commonly estimated from other atmospheric variables using parameterizations. A full atmospheric model such as WRF, in contrast, provides ILWR directly through its radiative-transfer calculations.

As a simple research example, AWSOME was used to run SNOWPACK over the same locations and meteorological forcing while varying only the source of ILWR (AWSOME Core Team 2026). A WRF simulation provided the reference forcing, while four established ILWR parameterizations were applied as alternative treatments. Cloud-cover information required by the all-sky parameterizations was assimilated from Open-Meteo. Incoming shortwave radiation was withheld from all treatments and generated identically by MeteoIO, isolating the effect of the different ILWR estimates as far as possible.

Each treatment produces the same xsnow data structure and can therefore be combined along a realization dimension and compared directly using the usual AWSOME analysis and visualization tools. This example illustrates how components normally used independently—WRF, external meteorological data, parameterizations, SNOWPACK, and xsnow—can be assembled into a reproducible experiment without building a dedicated modeling chain for each treatment:

```
# WRF reference + four ILWR parameterizations
treatments = [
    "WRF", "KONZELMANN", "OMSTEDT",
    "BRUTSAERT", "DILLEY"
]
forcing = wrf_forcing(points, period)
forcing = assimilate_cloud_cover(forcing)
runs = {}

for treatment in treatments:
    if treatment == "WRF":
        experiment = forcing
    else:
        experiment = fill_ilwr(
            forcing,
            model=treatment,
            overwrite=True
        )

    # generate identical shortwave forcing
    experiment = experiment.drop_vars(["ISWR"])
    runs[treatment] = run_snowpack(experiment)

results = combine(runs, dim="realization")
```

## 8. OPERATIONAL EXAMPLE

As an operational example, consider a warning service that wants continuously updated simulations for a forecast area that does not coincide with any predefined region. The area of interest is simply drawn by hand in any GIS or web mapping tool and exported as a GeoJSON polygon—the only site-specific input the workflow requires. A recipe references this polygon, and AToolchain tessel-

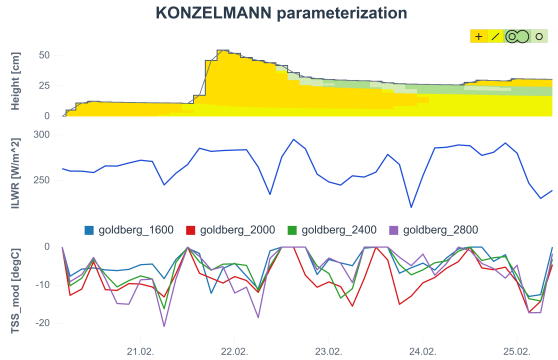



Figure 6: The ILWR experiment explored in nivix for the Konzelmann parameterization. The view combines modeled stratigraphy and incoming longwave radiation for the selected realization with the resulting snow-surface temperatures across all simulated locations, allowing forcing differences and their snow-cover response to be examined together.

lates it into terrain aware tiles with one simulation point per tile, downloading the required elevation data automatically:

```
# area.yaml (excerpt)
gridded:
  run:
    date_opera: now
  locations:
    builder: voronoi
    regions:
      file: forecast_area.geojson
    dem: download
  data:
    sources:
      - name: history
        source: openmeteo
        role: backfill
        window: {mode: season}
      - name: forecast
        source: openmeteo
        role: update
        window: {mode: operational,
                 days_past: 2, lead_time: 3}
  snowpack:
    flavor: nwp
    resume: true
  indices: [rc_flat, sk38, lwc, punstable]
```

The backfill source reconstructs forcing for the season, while the forecast source updates only the most recent period and extends it into the forecast horizon. On the first invocation, the chain initializes the season from bare ground; later runs continue from the stored SNOWPACK state and update only what has changed. Operational deployment therefore reduces to scheduling the same command used for the initial run:

```
# crontab
30 5 * * * aw run /opt/awsome/area.yaml
```

The framework handles the remaining orchestration, including parallel execution, logging, and recovery from incomplete data. Each morning, the forecaster finds updated stability indices for the area on the dashboard (Figure 4) and can explore the underlying stratigraphy in nivix.

## 9. CONCLUSION

AWSOME has matured into a framework that can support snow-cover modeling from small research experiments to continuously running operational applications. Its main contribution is not a single model or algorithm, but the integration of data access, model execution, post-processing, visualization, and deployment into a common environment.

By moving much of the recurring technical integration work into shared and reusable components, AWSOME reduces the effort required to turn a modeling idea into a reproducible workflow. The same tools and data structures can then be carried forward as experiments grow in scale or move towards operational use.

This is particularly valuable in a field where many technically demanding steps are repeated across institutions and projects. AWSOME aims to make these efforts reusable, lower the barrier to working with advanced snow-cover models, and provide a common foundation on which new methods, models, and operational applications can be developed collaboratively.

## ACKNOWLEDGEMENTS

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AWSOME would not have been possible without the sustained efforts of snow and software enthusiasts making the most of the resources available to them, and more. We gratefully acknowledge the Avalanche Warning Service Tirol for providing the largest share of financial support and enabling developments beyond its immediate operational needs, allowing AWSOME to serve a broader community. We also thank Norwegian Water Resources and Energy Directorate NVE, GeoSphere Austria – including the Avalanche Warning Service Salzburg – and the wider consortium of Austrian Avalanche Warning Services for their support,

ideas, and sister software projects.

Finally, we thank Open-Meteo for providing freely accessible, high-quality meteorological data, enabling rapid worldwide development, testing, and potential operational use of AWSOME.

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