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COMPUTING

Building NEXhub: an infrastructure for the future of IFS experimentation

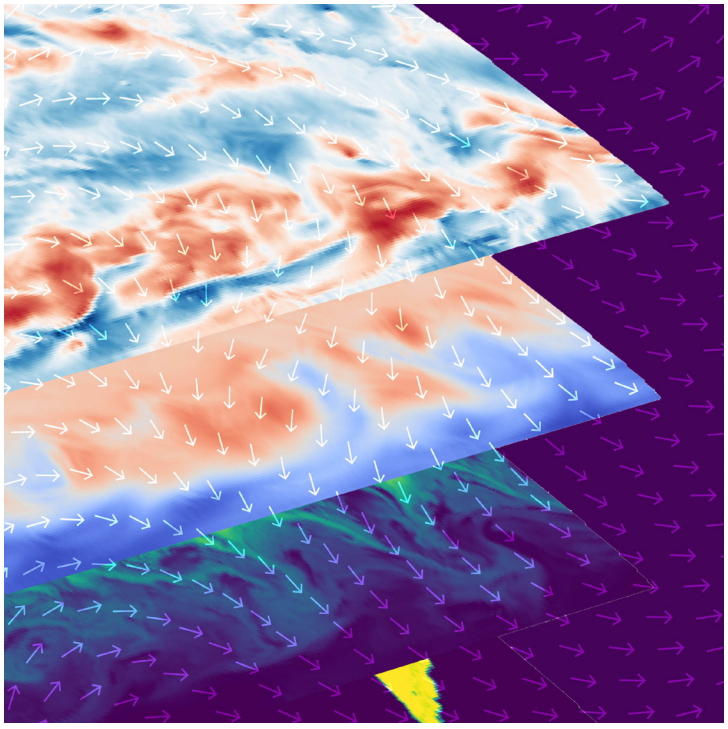

Illustration of the Anemoi ERA5 dataset

www.ecmwf.int/en/about/media-centre/media-resources

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Building NEXhub: an infrastructure for the future of IFS experimentation

Paul Burton, Paolo Battino, Michael Sleigh, Cihan Sahin

In the fields of numerical weather prediction (NWP) and scientific computing, the development of new technologies is often driven by an urgent need to keep pace with growing computational demands and increasingly complex workflows. As forecasting systems become more sophisticated, their supporting tools must evolve in tandem. At ECMWF, this has culminated in the development of NEXhub (Numerical Experiment Hub). This user-centric platform is modern, reliable and thoroughly tested, with an up-to-date, well-supported software infrastructure.

While the initial focus is on the transformation of the management of Integrated Forecasting System (IFS) experiments for researchers at ECMWF and in our Member States, the system is designed with flexibility in mind to enable it to be applied to other computational science projects in the future.

Here we present an in-depth overview of NEXhub, covering the motivation for its creation, the technical foundations it builds on, its core components and the development process that made it possible.

ECMWF's FORGE initiative

The creation of NEXhub falls under the umbrella of ECMWF's Forecast-System Regeneration (FORGE) initiative (Sleigh et al., 2025). FORGE is designed to modernise the IFS and its associated infrastructure, ensuring that it maintains high computational performance on modern architectures, and is sustainable and adaptable in the face of rapidly advancing computational landscapes. NEXhub addresses these challenges by providing a system that is scalable, portable and enables ECMWF to take full advantage of cloud-centric and distributed computing environments.

The motivation behind NEXhub

The need for NEXhub became increasingly apparent as limitations in the legacy PrepIFS software surfaced. Developed in 1999 to facilitate the configuration of the increasingly complex IFS system (Wedi et al., 1999), PrepIFS is a Java-based graphical user interface. It has become difficult to maintain and enhance using internal ECMWF resources and is poorly suited for contemporary user requirements. Additionally, the migration of ECMWF's high-performance computing facility to Bologna, combined with new opportunities to use multiple EuroHPC platforms within the European Commission's Destination Earth (*https://www.ecmwf.int/en/about/what-we-do/environmental-services-and-future-vision/destination-earth*) initiative, underscored the need for a more accessible, web-based alternative.

The design of NEXhub addresses these constraints by supporting a distributed user base of both ECMWF and Member State developers, accommodating remote access from portable devices and offering increased potential for collaboration between ECMWF teams.

Collaborative development and agile approach to integration

NEXhub is the result of a successful cross-ECMWF collaboration. The vision and requirements were shaped through joint sessions involving a range of stakeholders, including the Centre's operations and research teams, external users of IFS and users of the forecasting system.

A key element of the development process was direct engagement with an external software consultancy, Oxidian. Their consultants worked closely with in-house developers, bringing expertise in both front-end and back-end development, and using an agile approach. This enabled rapid prototyping and continuous integration of user feedback.

Close involvement with internal developers ensured alignment with ECMWF's requirements and existing infrastructure. The combined expertise of internal stakeholders and external specialists accelerated delivery and strengthened the system through collaborative review and early detection of potential problems and incompatibilities between parallel developments.

This journey has culminated in a flexible, modern and user-centric platform that will replace the long-standing PrepIFS system, provide additional functionality and, in the longer term, improve other parts of the IFS developer workflow.

Multiple applications with a seamless user experience

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From a web development perspective, NEXhub is designed as a suite of independent applications that are seamlessly integrated and presented to the user as a single, coherent interface. A major challenge in achieving this unified experience is handling authentication across multiple applications. Standard single sign-on mechanisms, while effective in managing credentials, do not synchronise session states across applications because every application initiates a session at a different time and keeps track of it separately. This often results in users being repeatedly logged out and so degrading their experience.

To mitigate this, an approach that uses one central system to manage user sessions was adopted. Called a gateway application, this system oversees each user's session and passes their requests to the various NEXhub components (Figure 1).

This design ensures all the applications recognise a user session while maintaining the convenience of a one-time login. A custom Python library was developed to manage this authentication layer. Importantly, this user session mechanism works alongside the native authentication systems of individual applications, allowing them to function independently outside of NEXhub if needed.

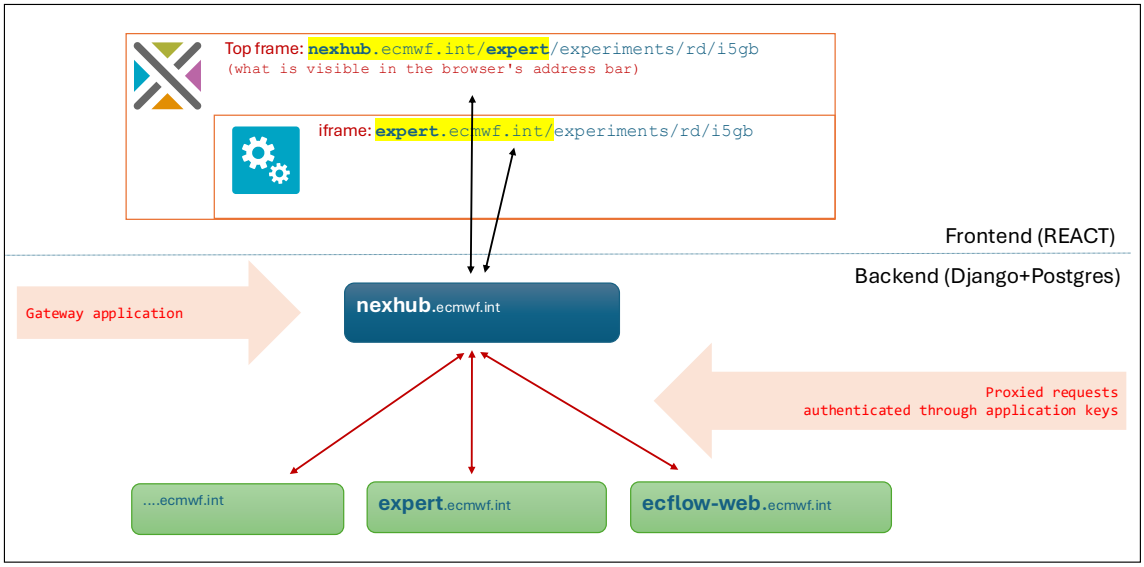

FIGURE 1 Diagram depicting how the application running on nexhub.ecmwf.int acts as a gateway to other applications.

Modern backend and deployment architecture

Each application within NEXhub provides a rich, multifunctional, interactive user interface. RESTful APIs are used to exchange information, enabling integration with text-based command line interface tools and external systems.

Each application runs in its own self-contained and reproducible environment – referred to as pods – allowing multiple versions to operate in parallel. This not only ensures operational redundancy but also enables zero-downtime updates: new versions are activated only once fully operational, after which older pods are retired. This also means that new pods can be added to the system if performance degrades below a certain threshold.

Any changes made to the system are automatically tested within a dedicated staging environment. Continuous deployment and Continuous integration (CD/CI) pipelines, managed via GitHub, verify the quality and integrity of each release, ensuring a high level of software reliability.

Transitioning legacy systems to web-based services

A notable engineering challenge was the transition from a legacy, filesystem-dependent ecosystem to a fully web-based model. This was particularly the case for PrepIFS, which functioned as a standalone Java application and relied on numerous locally accessible scripts and directories.

One example is the handling of experiment identifiers, known as 'expvers'. Previously, a Perl script was responsible for issuing new identifiers that were tracked via a filesystem-based index. In NEXhub, this mechanism has been re-implemented as a web service, known as the 'expver-service', which can be

queried by any application using simple HTTP requests.

Maintaining backward compatibility with PrepIFS during the migration to its replacement app within NEXhub – known as ExpERT – presented another challenge. To support both systems, a secure bridging mechanism was created to link the two. A wrapper script was developed to act as an intermediary, allowing the legacy PrepIFS environment to interact securely with the web-based expver-service. This script uses short-lived authentication tokens that mitigate security risks even when stored in user-accessible locations. This setup, operational since autumn 2024, will be phased out alongside the retirement of PrepIFS, at which point expver-service will continue to function as a standalone, fully web-based utility.

Core features and capabilities

NEXhub's 'apps' allow users to access different elements of the IFS developer workflow. At launch, NEXhub included two core applications:

- **ExpERT (Experiment Edit and Run Tool):** Replaces PrepIFS by enabling experiment configuration, validation and submission.
- **ecFlow Viewer:** A read-only tool that allows users to monitor experiment progress on ecFlow.

The modular design ensures that new components can be introduced independently. Planned additions include:

- **DLM (Data Lifetime Manager):** Supports dataset lifecycle management, especially for tape-based assets, such as the Meteorological Archival and Retrieval System (MARS) and ECMWF's File Storage system (ECFS).
- **Performance Analyser:** Enables storage, visualisation and comparison of IFS system performance metrics.
- **Visualisation Tool:** Facilitates creation and sharing of diagnostic plots from experimental data.
- **Quaver:** Provides tools for comparing experimental outcomes with operational model results.
- **IVER:** Offers detailed comparative analysis of experiments against either the operational analysis or the experiment's own analysis.

These tools are designed to streamline the processes of setting up, running and analysing experiments. They also aim to support the integration of research developments into production environments and lower technical entry barriers for users who wish to contribute to IFS development.

There are plans to make NEXhub and select components available as open-source projects, with the goal of maintaining flexibility and compatibility with different modelling frameworks. Other sites will be able to integrate additional components tailored to their own workflows and requirements.

ExpERT: bridging familiarity and innovation

ExpERT is the flagship application within NEXhub that replaces PrepIFS. On login, users are presented with a dashboard for easy access to recently viewed or submitted experiments. Users can also navigate to the Experiment Browser, which includes powerful filtering tools and metadata tagging for more efficient organisation, and to aid the discovery of other users' experiments to aid collaborative working practices.

Core functionalities include:

- Creating new experiments or generating copies of existing experiments.
- Comparing experiments, using clearer visualisation tools than PrepIFS offered.
- Editing experiments, using an interface familiar to PrepIFS users, featuring panels with collections of related variables on the left side of the screen and corresponding variable lists on the right (Figure 2). This design supports a seamless transition for users by providing familiarity while also introducing enhanced functionalities to address previous system limitations without unnecessarily complicating the user experience.
- Rule-based checks ensuring consistency and validity. In certain cases, these checks automatically adjust settings; for instance, the number of central processing units required is set according to the resolution of the IFS experiment and the specified high performance computing machine. With hundreds of automated validations available, this functionality enables both novice and experienced users to achieve optimal, reliable configurations. ExpERT further enhances the 'checks' process by

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providing users with a succinct summary of proposed changes and the option to accept or reject them.

- Publishing experiments, making them visible to other users and eligible for submission.

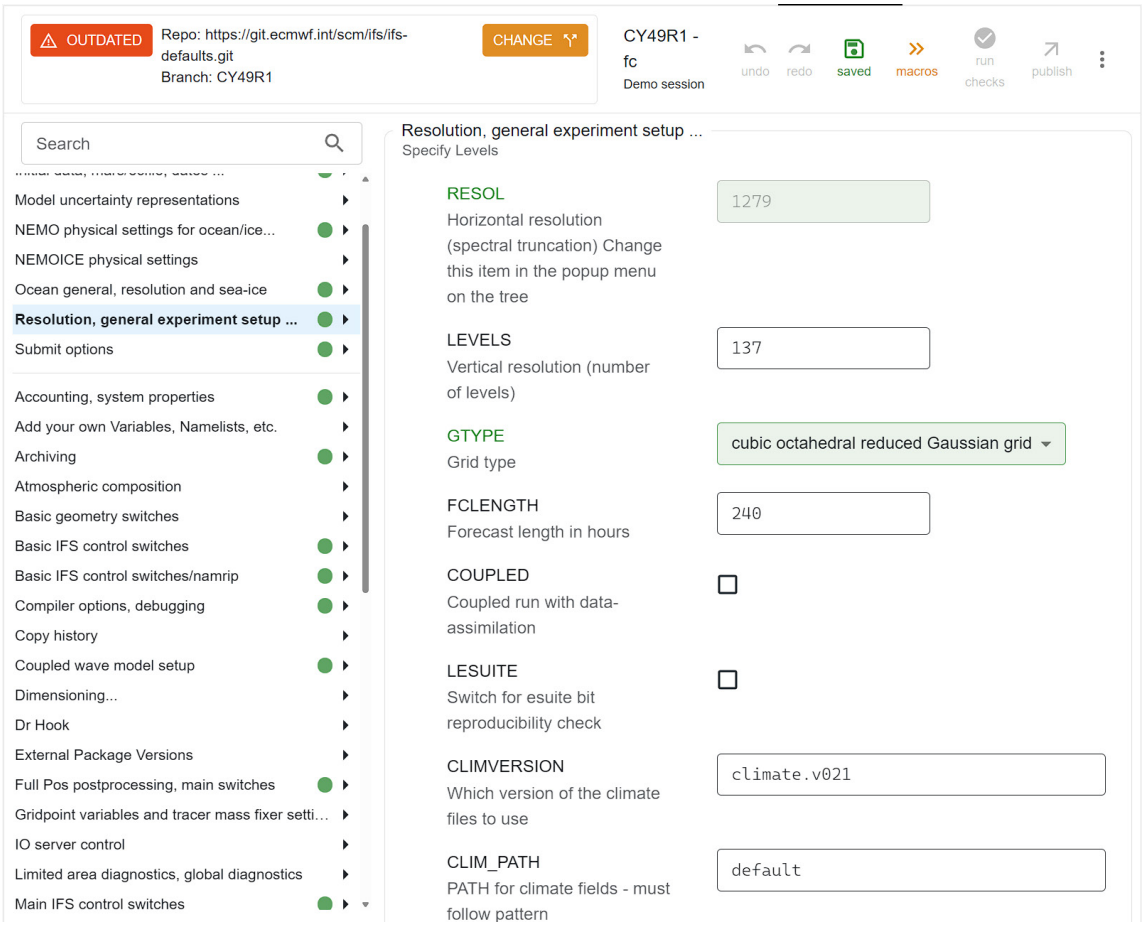

FIGURE 2 Screenshot of the ExpERT user interface, with panels of related variables on the left side and corresponding variable lists on the right, a similar layout to PrepIFS.

Differences from PrepIFS

ExpERT has some noticeable enhancements compared to PrepIFS, which both improve its usability and reduce the chance of unnoticed errors or of users making mistakes.

As a web application, ExpERT can be run from any major web browser, anywhere in the world, making it highly accessible.

The state of an experiment is preserved on ECMWF web servers and updated every few seconds. This means a user can access their work from any machine, simply by logging on and opening the experiment they were working on.

The ‘published’ states are stored long term, so it is possible to view and optionally revert to a previous published state. This means, for example, it is always possible to see the precise configuration used by a previous submission of an experiment and then compare it to the current configuration to understand what has changed.

A comprehensive command-line interface, mirroring many of the significant ExpERT capabilities, allows users to carry out most functions from a terminal, or automate them using a shell or Python script. For example, a CI system is implemented for IFS that uses the command-line interface to copy then update experiments, run checks, and submit them.

A vital innovation is the use of a specific version-controlled schema for each experiment. This schema is a machine-readable description of all the parameters defining an experiment and the checks.
The schema is contained within a linked Git branch, allowing changes to be carefully tracked and merged. When this branch is updated, ExpERT notifies users, who can decide whether to adopt the latest schema changes after being shown the effect it will have on their experiment.

Migration from PrepIFS

Command line tools are provided that allow users to move PrepIFS experiments into ExpERT. In the first two months after the launch of NEXhub in June 2025, users migrated over 2,880 experiments. The feedback to the developers from these early migrations has led to many enhancements in usability, stability and functionality.

After allowing users to migrate their experiments, the ability to submit recent IFS cycles from PrepIFS will be discontinued by the end of 2025. Older cycles, for example those related to the ERA5 reanalysis, will be supported on PrepIFS until the current high-performance computing facility is replaced, but within the next facility, only ExpERT will be available for managing and submitting experiments.

Future ExpERT enhancements

Over the coming years, the schema format used to represent the variables ExpERT can configure will be updated from the current PrepIFS XML format to a more modern JSON format. This will support new features that will further improve the usability and functionality of the interface. The check rules, which are currently expressed in a proprietary PrepIFS specific language, will be moved to a Python environment, to allow a more comprehensive and efficient evaluation of the rules.

The updated schema will be able to support complex multi-function experiments, which are required to reproduce the production forecast system. This will enable research teams to more comprehensively test changes in a production-like environment, both speeding-up and de-risking the process of passing changes from a research environment into production. The flexibility of the new schema will also support Artificial Intelligence Forecasting System (AIFS) experiments.

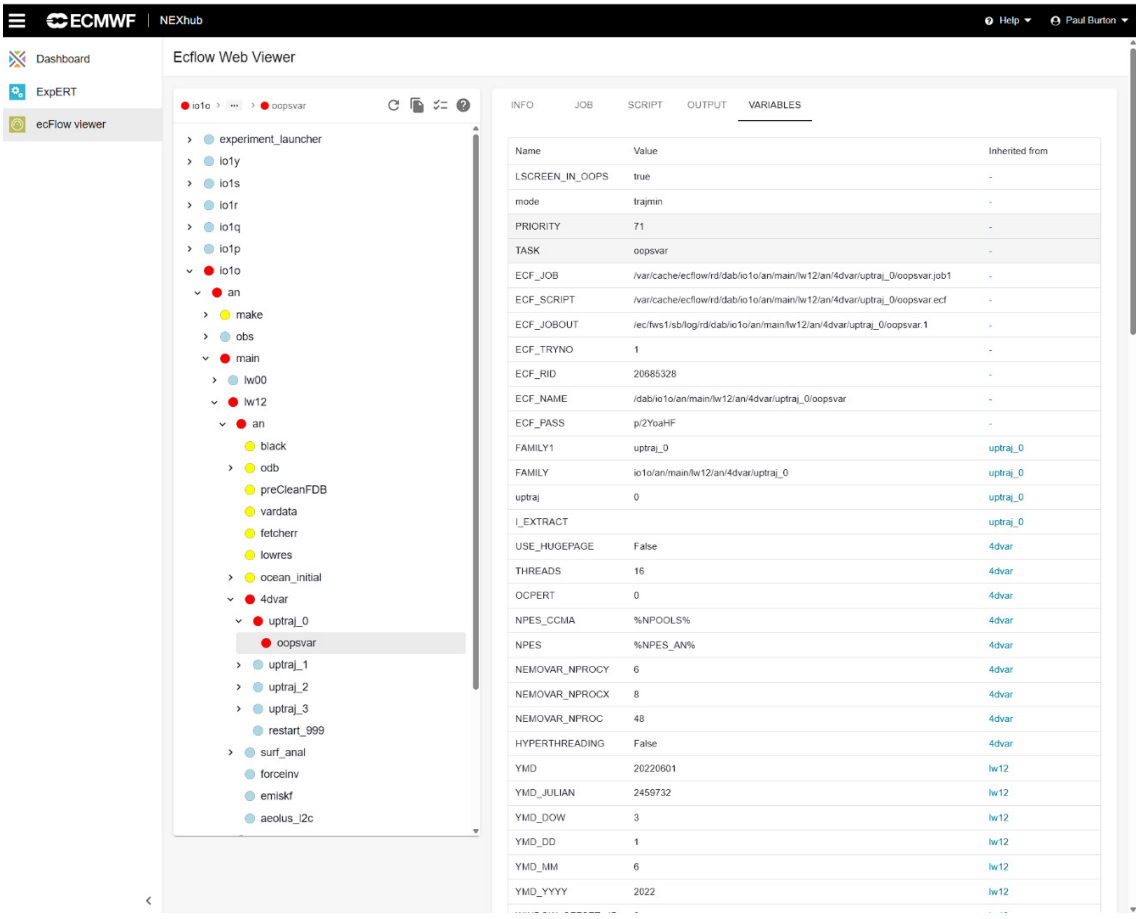

FIGURE 3 Screenshot of the ecFlow Viewer user interface, showing details of a selected task of a typical experiment.

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ecFlow Viewer: remote monitoring in real time

The ability for users to monitor their experiments directly from a web browser is a welcome improvement, especially when remotely monitoring lengthy integrations.

Whilst the current functionality of this NEXhub component is restricted to a read-only interface (Figure 3), future iterations will allow users to interact with their experiments – for example, restarting a task that has failed or changing the value of a configuration variable in a live experiment.

Running experiments on external HPC platforms

NEXhub has been designed to support the easy submission of experiments on remote (non-ECMWF) HPC platforms. This ensures, for example, that researchers can simply submit experiments to any of the EuroHPC machines available within the EU Destination Earth initiative. Using PrepIFS, there was no straightforward way to achieve this, and users had to manually transfer PrepIFS configuration files to the remote machine before correctly configuring the ECflow suites to run the experiment.

Community involvement and user feedback

Throughout NEXhub's development, community involvement, both within ECMWF and with our external users, has been vital. Selected users were invited to test early builds, provide structured feedback and help prioritise new features. A launch seminar in June 2025 included live demonstrations, migration guidance and access to comprehensive documentation.

Resources such as user guides, FAQs and training videos are maintained on ECMWF's Confluence platform to assist users in their transition to NEXhub. This commitment to transparency and knowledge sharing exemplifies the project's inclusive ethos.

Cultural shift: beyond technological modernisation

NEXhub is more than a toolset; it reflects a cultural shift within ECMWF and the broader meteorological community. By embedding principles of transparency, reproducibility and collaboration, NEXhub empowers users to concentrate on scientific objectives rather than facing challenging technical barriers.

The platform's integration of modern software practices with domain-specific requirements positions it as a foundational asset for current and future forecasting systems. Its design encourages cross-disciplinary engagement and lowers the barrier to entry for new contributors.

Conclusion: a platform for the future

NEXhub marks a significant step forward in the evolution of ECMWF's research developer's workflow. It addresses the limitations of legacy systems through a unified, extendable and user-informed architecture built on modern software principles. With components like ExpERT and ecFlow Viewer already operational and more in the pipeline, NEXhub is set to become a central hub for numerical experimentation at ECMWF.

In embracing NEXhub, ECMWF not only equips its users with powerful new tools but also paves the way for a more collaborative, transparent and future-ready scientific ecosystem.

Try it for yourself

All users with an ECMWF login and permissions to run PrepIFS experiments can now start to use NEXhub by visiting *https://nexhub.ecmwf.int/.*

Users with access to NEXhub can explore a wealth of user documentation at *https://confluence.ecmwf.int/display/NEXHUB/NEXhub+User+Documentation+Home*

Further reading

Sleigh, M., A. Bennet, P. Burton, P. Cresswell, P. Gillies, A. Hill, Z. Kipling, et al., 2025: Modernisation of the Integrated Forecasting System. *ECMWF Newsletter* No. 182, 19–23. *https://doi.org/10.21957/m9ad5hv72s*

Wedi, N., 1999: PrepIFS - Global modelling via the Internet, *ECMWF Newsletter* No. 83, 7–10. *https://www.ecmwf.int/sites/default/files/elibrary/041999/14641-newsletter-no83-spring-1999_1.pdf*

The backend services of NEXhub are built using the Django framework and supported by PostgreSQL databases, a common stack within ECMWF's User Applications and Services Team. Frontend interfaces are developed in TypeScript using the React library.

All applications are containerised using Docker and deployed on a Kubernetes cluster.

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