

Newsletter

No. 185 | Autumn 2025

Monitoring heat and cold stress

A new era for CEMS flood forecasting

AIFS ENS becomes operational

Upgrade to IFS Cycle 50r1

Building NEXhub

Ten years of climate monitoring

© Copyright 2025

European Centre for Medium-Range Weather Forecasts, Shinfield Park, Reading, RG2 9AX, UK

The content of this document, excluding images representing individuals, is available for use under a Creative Commons Attribution 4.0 International Public License. See the terms at <https://creativecommons.org/licenses/by/4.0/>. To request permission to use images representing individuals, please contact pressoffice@ecmwf.int.

The information within this publication is given in good faith and considered to be true, but ECMWF accepts no liability for error or omission or for loss or damage arising from its use.

Publication policy

The ECMWF Newsletter is published quarterly. Its purpose is to make users of ECMWF products, collaborators with ECMWF and the wider meteorological community aware of new developments at ECMWF and the use that can be made of ECMWF products. Most articles are prepared by staff at ECMWF, but articles are also welcome from people working elsewhere, especially those from Member States and Co-operating States.

The ECMWF Newsletter is not peer-reviewed.

Any queries about the content or distribution of the ECMWF Newsletter should be sent to Chelsea.Snell@ecmwf.int

Guidance about submitting an article and the option to subscribe to email alerts for new Newsletters are available at www.ecmwf.int/en/about/media-centre/media-resources

A milestone year and a moment of reflection



This year marks fifty years since ECMWF was established – half a century of scientific collaboration and innovation across our Member and Co-operating States. With celebratory events held in Bonn, recently in Bologna and soon to take place in Reading, this anniversary has offered us an opportunity to look back at how far numerical weather prediction and related sciences have come, and to look ahead to how ECMWF will continue to evolve.

The articles in this issue reflect that ongoing journey – one that is deeply rooted in science and continually reaching towards the future.

The spirit of innovation is evident in the operationalisation of the Artificial Intelligence Forecasting System ensemble (AIFS ENS), marking another significant milestone in the integration of machine learning within numerical weather prediction. As previously announced in the Summer Newsletter and described in more detail in this issue, AIFS ENS is trained using a CRPS-based approach, which optimises the probabilistic scores of the ensemble forecasts. It delivers skilful weather forecasts with significantly improved speed and energy efficiency. Alongside it, the upgrade to IFS Cycle 50r1 highlights how we continue to strengthen our traditional forecasting system, ensuring that physics-based and AI-driven approaches advance together.

Our feature article on the Copernicus Climate Change Service (C3S) looks back on a decade of climate monitoring. Over those ten years, C3S has transformed climate monitoring, providing timely, transparent and accessible reporting – covering what have now become the ten warmest calendar years on record globally. From monthly bulletins to interactive applications like Climate Pulse, C3S has become a trusted reference for policymakers, scientists and citizens to understand the accelerating pace of climate change and is a remarkable example of what collaboration can achieve.

Looking to the future, NEXhub represents a significant step in managing numerical experiments within our computing

infrastructure or EuroHPC machines available under the DestinE initiative – it is a platform designed to enable faster testing, development and collaboration.

The news stories in this issue demonstrate the breadth of ECMWF's work – from working with partners for expanding observation coverage across the Mediterranean or verifying forecasts over South America to exploring innovative ways of understanding health-related weather impacts. They underline the power of data and partnerships to advance global forecasting and applications that matter to people's lives.

For me, this anniversary year and this Newsletter hold particular significance, as they are my last as Director-General before I retire at the end of 2025. It has been an immense privilege to serve an organisation that embodies international collaboration and scientific excellence, and to work alongside such dedicated colleagues and partners in the European Meteorological Infrastructure. I am deeply proud of what ECMWF has achieved during these transformative years. We have moved to a full ensemble Earth-system approach and assimilated new observations. We have embraced AI and machine learning, implemented cloud services and open data, and worked with the EU and partners to consolidate our Copernicus services and to establish Digital Twins for Destination Earth. In addition to this, we have transitioned to a multi-site organisation and are making progress in inclusion and diversity.

As ECMWF enters its next chapter, I have every confidence that it will continue to thrive under Florian Pappenberger's leadership, who will bring expertise, passion and dedication to his new role. I wish him and all of you every success in the years ahead.

Florence Rabier
Director-General

Contents

Editorial

A milestone year and a moment of reflection 1

News

Code for Earth 2025: innovation, collaboration and impact . . 3

Thermal Trace: health-related weather and climate monitoring 5

European open data for machine learning applications 6

Increasing observation coverage in the Mediterranean 8

AI takes CEMS flood forecasting into a new era 9

Anemoi training-ready version of ERA5 now open to all . . . 10

Low-cost weather stations improve weather services in Tajikistan 11

Verification of global and regional NWP models over South America 13

A new index to provide early alerts for extreme precipitation 15

Extreme wildfires in summer 2025 16

The introduction of waves in sea ice 18

Earth system science

AIFS ENS becomes operational 20

Upgrade to IFS Cycle 50r1 25

Looking back on 10 years of climate monitoring by the Copernicus Climate Change Service 34

Computing

Building NEXhub: an infrastructure for the future of IFS experimentation 42

General

ECMWF publications 48

ECMWF Calendar 2025 48

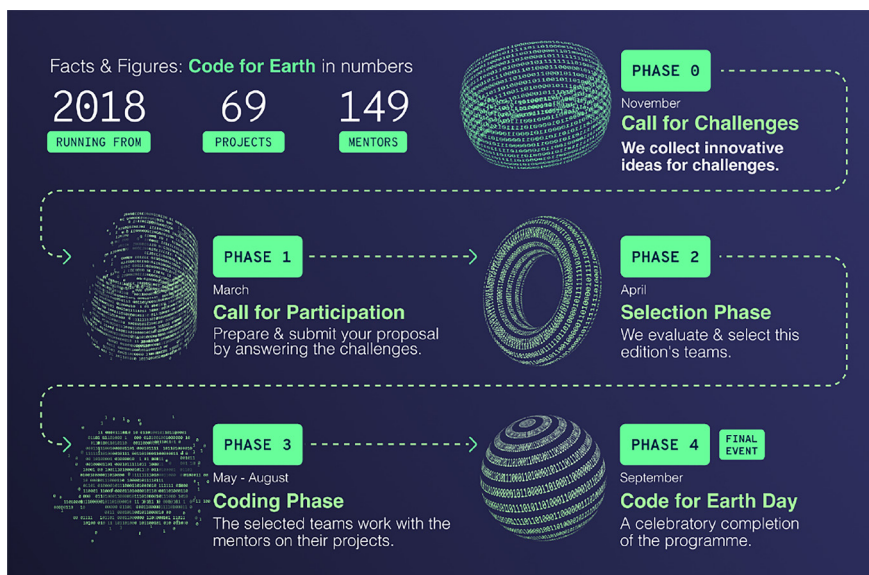
Contact information 49



Editor Annabel Cook • **Typesetting and graphics** Chris Matthews • **Cover** Illustration of the Anemoi ERA5 dataset.

Code for Earth 2025: innovation, collaboration and impact

Athina Trakas, Esperanza Cuartero



Code for Earth annual timeline. A timeline for Code for Earth, including some facts and figures for the programme.

Code for Earth returned in 2025 with ten exciting projects that united developers, scientists and innovators internationally to create open-source solutions addressing today's most pressing environmental and climate challenges.

Organised by ECMWF, including support from the Copernicus Climate Change Service (C3S), the Copernicus Atmosphere Monitoring Service (CAMS) and Destination Earth (DestinE), the programme invites each year selected external teams to collaborate with expert mentors from both ECMWF and partner organisations. The aim is to deliver solutions that improve how we use, visualise and interpret Earth science data.

A programme built on strong partnerships

Collaboration is at the core of Code for Earth. Each year, the programme works with partner organisations – so-called 'challenge partners' – from academia, research and industry, on selected projects, some of which are co-mentored by the partners. These

collaborations broaden the network of Code for Earth, fostering knowledge exchange and supporting meaningful innovation.

This year's edition involved four distinguished partner organisations, working with ECMWF experts to design and mentor three unique challenges:

International Foundation Big Data and Artificial Intelligence for Human Development (IFAB) (Italy)

Based in Bologna, IFAB is a non-profit foundation operating in the heart of Italy's 'Data Valley'. With strong links to high-performance computing, AI and sustainable innovation, IFAB acts as a bridge between research, technology and society.

Forschungszentrum Jülich (FZ Jülich) (Germany)

FZ Jülich is a German interdisciplinary research centre tackling societal challenges in energy, climate change and information. It is also a leader in supercomputing and Earth system science.

In this year's edition of Code for Earth, IFAB and FZ Jülich joined forces to

co-mentor the Physics-Aware Consistency Evaluator (PACE), a tool designed to evaluate how realistic machine learning-based weather forecasts are, addressing the crucial question of whether fast, data-driven models for weather forecasting can remain physically consistent, ensuring reliable outputs for both scientific and operational use.

Helmholtz Centre Hereon (Helmholtz-Zentrum Hereon) (Germany)

Hereon is one of Germany's leading research centres in environmental and coastal systems, with expertise spanning atmospheric and aquatic pollution, climate change and machine learning applications.

Hereon co-mentored the 2025 project AI4AirQuality: High-Resolution Air Pollution Downscaling. The project explored advanced machine learning architectures to downscale CAMS global data into higher-resolution insights. By focusing on feature selection, interpretability and scalability, this work contributes to more accurate, actionable urban air quality information.

European Network of Transmission System Operators for Electricity (ENTSO-E) (Europe)

ENTSO-E represents 39 electricity transmission system operators from 35 European countries, working to ensure reliable and sustainable electricity across the continent.

ENTSO-E co-mentored the project Weather-Energy Analysis & Visualisation for Extremes (WEAVE). WEAVE focused on developing an interactive platform to visualise the impact of extreme weather events on energy systems, using the Pan-European Climate Database and Jupyter Notebooks.

These collaborations exemplify ECMWF's role as a hub for scientific partnerships at all levels – international, interdisciplinary, and open-source.

2025 Code for Earth projects at a glance

Here’s a snapshot of this year’s projects, spanning across three key streams – Data Visualisation, Machine Learning, and Software Development – each addressing challenges in their fields:

AI4AirQuality: High-Resolution Air Pollution Downscaling	Focuses on refining air quality predictions via advanced ML-based downscaling techniques.
EarthReach Agent: Dual-LLM Framework for Validated Meteorological Chart Descriptions	Uses Large Language Models (LLMs) to generate validated textual descriptions of meteorological charts for visually impaired scientists.
EVALKIT: Model Error Detective	Produces tools to diagnose and visualise errors in modelling outputs.
Fire Front Radar	Designs an interactive web application for dynamically exploring fire-related data worldwide.
MLCosting	Produces an ML API plug-in that predicts Data Store System (DSS) request costs at ECMWF, improving efficiency.
OPEN DATA VISIO	Helps users access, download and analyse ECMWF real-time forecasts.
Physics-Aware Consistency Evaluator (PACE)	Develops metrics to assess how well ML models respect physical laws in meteorological predictions.
PolyShell	Offers a fast, efficient way to simplify complex polygonal data while preserving essential features.
Visualising CAMS Data in the Browser	Creates intuitive web-based tools for exploring Copernicus Atmosphere Monitoring Service atmospheric data.
Weather-Energy Analysis & Visualisation for Extremes (WEAVE)	Offers visual tools linking weather extremes to energy sector impacts.

More details on the projects, the participants, the mentoring teams and the programme in general are available on the Code for Earth website (https://codeforearth.ecmwf.int/projects/?_filter_by_date=2025).



Group photo. Participants in the 2025 Code for Earth Final Day in Bonn, Germany, in September 2025.

Partnerships at the heart of ECMWF’s mission

Code for Earth is more than an innovation programme – it is a demonstration of how ECMWF fosters impactful collaboration. By bridging expertise from multiple sectors in Earth sciences, ECMWF nurtures tools and solutions that benefit science, policy and society.

The programme continues to embody ECMWF’s vision of open, inclusive and future-ready scientific advancement.

Thermal Trace: health-related weather and climate monitoring

Matthew Menary, Rebecca Emerton, Chris Barnard, Anna Lombardi, James Varndell, Chiara Cagnazzo

Thermal Trace is a new interactive web-based tool, launched in August 2025, for monitoring heat and cold stress across the globe and how it has changed over time – from 1940 to five days behind real time: thermaltrace.climate.copernicus.eu

Thermal stress refers to the negative health impacts caused by exposure to extreme thermal conditions, for example during heatwaves and cold spells. This new app offers a practical tool for both climate monitoring and understanding the impact of weather and climate on health.

Users can use Thermal Trace to explore questions such as:

- Which locations have recently experienced extreme heat stress?
- What was the highest feels-like temperature during the heatwaves this summer?

- How many days of heat stress occurred in the month I was born?
- Over the last decade, how many tropical nights has my local area experienced each summer?
- How did last winter's cold stress compare to the long-term average?

The data behind Thermal Trace

The dataset used is the ERA5 reanalysis, primarily the ERA5-HEAT Universal Thermal Climate Index (UTCI) (<https://cds.climate.copernicus.eu/datasets/derived-utci-historical>). This represents a feels-like temperature, accounting for temperature, humidity, wind speed, solar radiation and how the human body responds to the thermal environment.

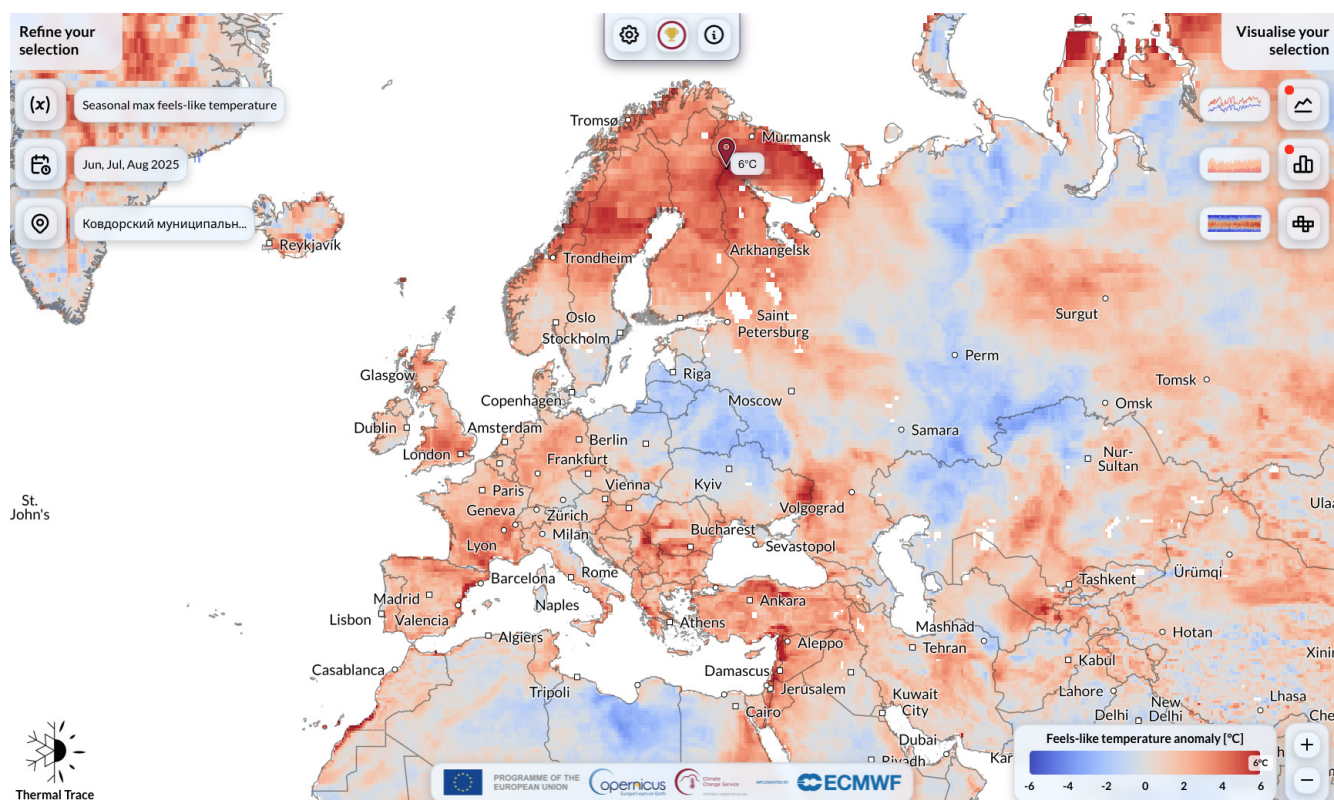
Thermal Trace provides intuitive information about heat and cold stress through interactive global maps and location-based charts. Users can

explore daily, monthly, seasonal, and annual maximum and minimum feels-like temperatures, the peak heat or cold stress category experienced, or the number of heat and cold stress days or tropical nights over a given period, as well as changes over time. The tool can also display these as anomalies relative to the average for the 1991–2020 reference period.

These statistics were also published in the Copernicus Climate Data Store (CDS) as part of the launch of Thermal Trace.

Powerful features and innovative design

Thermal Trace takes advantage of Zarr, a modern file format that makes it easy to store and quickly access large datasets over the cloud. This enables features such as real-time calculation of climatologies and extremes, and the



Screenshot from Thermal Trace. A map of anomalies in the seasonal maximum feels-like temperature (UTCI) for summer (June to August) 2025, relative to the average for the 1991–2020 reference period.

creation of bespoke maps based on user input.

With most Internet traffic now on mobile devices, Thermal Trace has been designed to work seamlessly on both mobile and desktop. The visual style follows modern design trends, such as a glass-like minimal user interface for a professional look. To help new users unlock the app's full potential, interactive tutorials with gamified elements make the learning process engaging and encourage exploration into the deeper functionality.

Users can search for a specific location or click or tap on the map to choose different time periods. The charts can be downloaded as images and the plotted data can be downloaded as csv files. In a coming update, Python notebooks will be added to further describe and demonstrate the data processing for maximal transparency. Comprehensive FAQs provide clear and accessible information.

Investigating summer 2025 in Europe using Thermal Trace

Summer 2025 saw heatwave conditions affecting many areas of Europe, and the maximum feels-like temperatures (UTCI) for the summer were generally above average, with northeastern Spain, southwestern France and much of Fennoscandia seeing some of the largest anomalies. Some of the highest numbers of heat stress days occurred in southern Spain and western Türkiye, with up to around 80 days of at least 'very strong heat stress' and a week of 'extreme heat stress'.

AEMET reported that Spain experienced its most intense heatwave on record in August, lasting 16 days. Thermal Trace indicates that feels-like temperatures reached up to 49°C in southern parts of the country, around 11°C above average. The threshold for 'extreme heat stress' – at which point it

is imperative to take actions to avoid heat stroke – is 46°C. This heatwave also impacted Portugal and France. More information can be found in the C3S monthly climate bulletin for August 2025 (<https://climate.copernicus.eu/climate-bulletins>).

By presenting decades' worth of data on thermal stress in an accessible way, Thermal Trace helps connect weather and climate with impacts on health, offering a new resource for research, planning, and awareness.

The content, design, implementation, technical infrastructure and dissemination of Thermal Trace result from a collaborative effort by colleagues across ECMWF, as entrusted entity for the Copernicus Climate Change Service (C3S), and were additionally supported by the Horizon Europe ASPECT project.

European open data for machine learning applications

Ana Prieto Nemesio, Zied Ben-Bouallègue, Florian Pinault, Pedro Maciel, Robert Osinski (all ECMWF), Annakaissa von Lerber (FMI), Marlies van der Schee (KNMI), Matthew Chantry, Umberto Modigliani (both ECMWF)

Meteorological data are recognised as highly valuable by the European Union (EU). New EU directives aim to make these data more accessible, fuelling artificial intelligence and data-driven innovation. In this context, RODEO (<https://rodeo-project.eu/>), a project funded by the EU and EUMETNET (<https://eumetnet.eu/>), has been established to enhance and unify open access to public meteorological data across Europe.

Within the framework of RODEO, two example datasets have been developed to demonstrate how open meteorological observations can be used in machine learning (ML) applications. Building on data curated by project partners, datasets have been designed with both domain expert and ML expert constraints and requirements in mind. They show how meteorological data can serve not only for training ML models but also for validating the quality of their output.

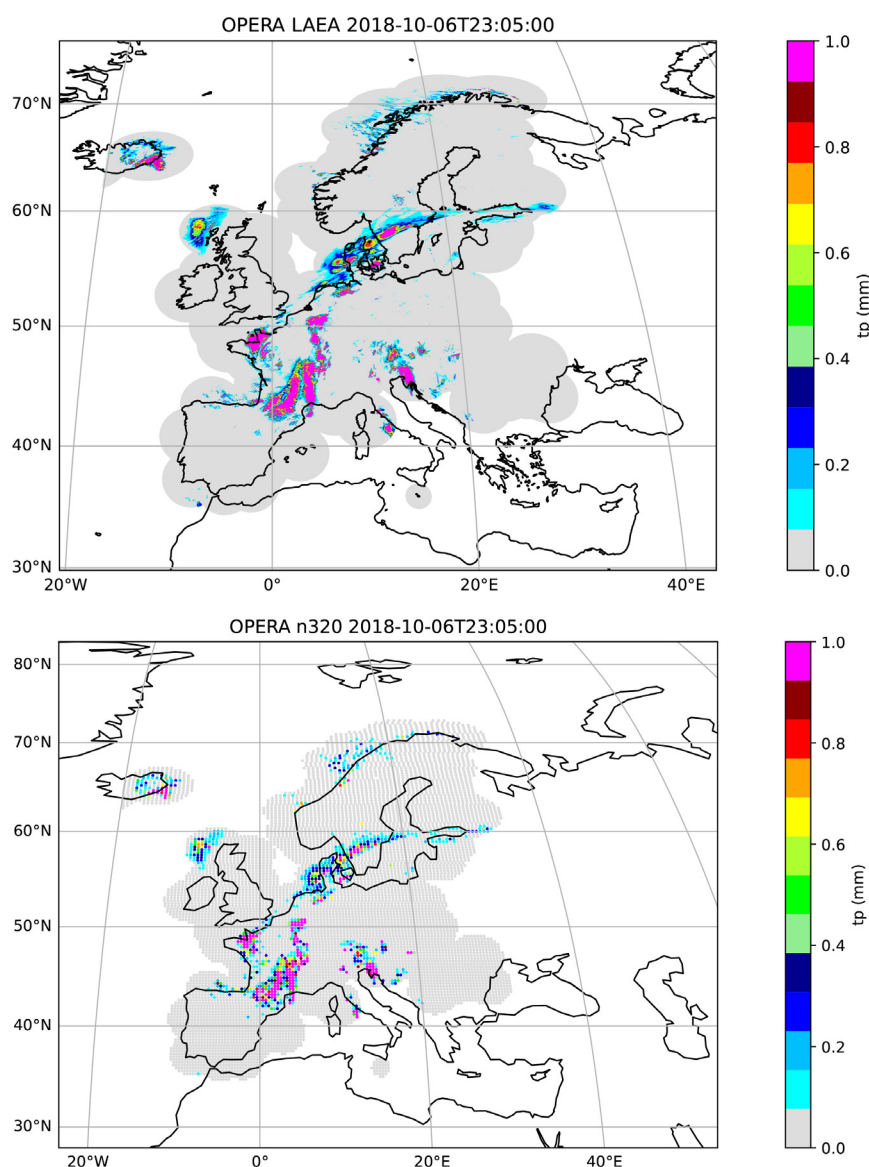
Weather data for ML training

The Operational Programme for the Exchange of weather Radar information (OPERA; <https://eumetnet.eu/observations/weather-radar-network/>), supported by EUMETNET, aims to harmonise and improve the exchange of weather radar information between national meteorological services across Europe. The OPERA pan-European 2D composites form a homogenised and consistent dataset with an archive of up to ten years.

In RODEO, different radar datasets based on OPERA were built to support a range of ML applications, such as nowcasting, medium-range forecasting (e.g. AIFS), and direct training from observations (e.g. Weather Generator). Covering the period 2013–2023, the datasets vary in spatial and temporal resolution to suit specific application needs.

The published datasets include both 1-hour and 6-hour accumulated precipitation. The 6-hour data are intended to align with popular reanalysis datasets, such as ERA5, used for medium-range forecast ML training.

Datasets are available at the native 2 km resolution, as well as at coarser resolutions reprojected onto reduced Gaussian grids, a type of grid used by the Integrated Forecasting System (IFS) and the AIFS, at O96 (approximately 1°) and N320 (approximately 31 km). Although coarsening can reduce some fine-scale features, these versions can significantly ease experimentation and exploration, particularly in the context of medium-range weather forecasting. Interpolation was performed using a conservative approach implemented in the Meteorological Interpolation and Regridding (MIR; <https://www.ecmwf.int/en/newsletter/152/computing/new-ecmwf-interpolation-package-mir>) package to ensure consistency of



Precipitation composites. Example of OPERA data showing total precipitation (tp) composites for 6 October 2018 at 23:05 UTC. Projection on the original grid (LAEA – Lamberth Azimuthal Equal Area) (top) and after interpolation to an N320 grid using MIR (bottom).

precipitation totals between the original and reprojected fields.

As MIR requires input data in GRIB2 format, the original HDF5 data were re-encoded accordingly. This not only enabled MIR-based reprojection but also makes it simpler to ingest OPERA data into the ECMWF MARS archive, improving user accessibility and reproducibility.

Access to the OPERA dataset is provided through Anemoi (<https://www.ecmwf.int/en/newsletter/181/news/introducing-anemoi-new-collaborative-framework-ml-weather-forecasting>), an open-source framework co-developed by ECMWF and several European national meteorological services. The primary

objective of Anemoi is to empower meteorological organisations to train ML models using their own data, simplifying the process through the provision of shared tools and workflows.

Climate statistics for ML forecast verification

The European Climate Assessment and Dataset (ECA&D; <https://www.ecad.eu/>) receives daily in situ meteorological surface observations data for 13 climate variables. It currently contains around 24,500 stations from 89 participants across 65 countries. The data, which are free for research and educational purposes, serve as the backbone for the ‘Climate node’ of the World Meteorological Organization Region VI

that provides climate services for regional monitoring. In RODEO, a dataset based on ECA&D was designed for applications in forecast verification. Targeted at ML developers, the data are provided alongside dedicated verification scripts for assessing precipitation forecasts over Europe. The data not only consist of observations but also of climate statistics necessary for computing state-of-the-art verification metrics, such as the Stable and Equitable Error in Probability Space (SEEPS), a performance measure used at ECMWF as a supplementary headline score. Calculating this score is not straightforward because it requires prior knowledge of the precipitation climatology at each station where the forecast is verified.

The verification dataset is called SEEPS4ALL and contains the information needed to compute the SEEPS score and local climate percentiles for computing other scores and skill measures. Climate statistics are crucial for assessing forecasts of extreme precipitation and high-impact events, and this is showcased with verification scripts for both deterministic and probabilistic forecasts.

In the ML community, benchmarking is widely recognised as a key driver of progress. With SEEPS4ALL, benchmarking of daily precipitation forecasts against in situ observations over Europe is promoted.

As part of the RODEO project, it has been shown how European open meteorological data can be transformed into practical, ML-ready datasets. At a time of extraordinary innovation, RODEO has demonstrated the value of collaboration for developing datasets and facilitates not only the access but also the use of open weather data.

Data access

The RODEO-ML datasets are publicly available under their respective licences and can be downloaded from the S3 bucket: s3://ecmwf-rodeo-benchmark. The accompanying code repository at <https://github.com/ecmwf/rodeo-ai-static-datasets> provides detailed instructions on downloading the datasets, along with examples and guidance on using the OPERA for Machine Learning applications and the ECA&D datasets for verification.

Increasing observation coverage in the Mediterranean

David Lavers (ECMWF), Pierre-Marie Poulain (OGS), Emanuela Clementi (CMCC), Milena Menna (OGS), Viviana Piermattei (CMCC), Olivier Desprez de Gésincourt, Sébastien Pere (both Météo-France, E-SurfMar), Carlo Cacciamani, Lina Porciello, Davide Giacomo Pagliaro (all Ag. Italia Meteo), Paolo Oddo, Nadia Pinardi (both University of Bologna), Anna Wilson, Luca Centurioni (both Scripps Institution of Oceanography)

Throughout September and October 2025, 15 drifting buoys are due to be released into the Ionian Sea and central Mediterranean. These buoys provide valuable sea-level pressure observations in a region with few in situ observations and where recent extreme events have occurred, such as Storm Daniel in September 2023, which makes this an important deployment for weather forecasting activities. The buoys can operate for up to two years, depending partly on the ocean currents and eddies, and are a cost-effective component of the global observing system.

How the deployment came about

In February 2025, a meeting was hosted at ECMWF's data centre in Bologna, where partners from organisations in Italy, the Scripps Institution of Oceanography at the University of California, San Diego, and the EUMETNET Surface Marine programme (E-SurfMar) came together to discuss opportunities for augmenting the current observation network across the Mediterranean Sea. During the meeting, there were

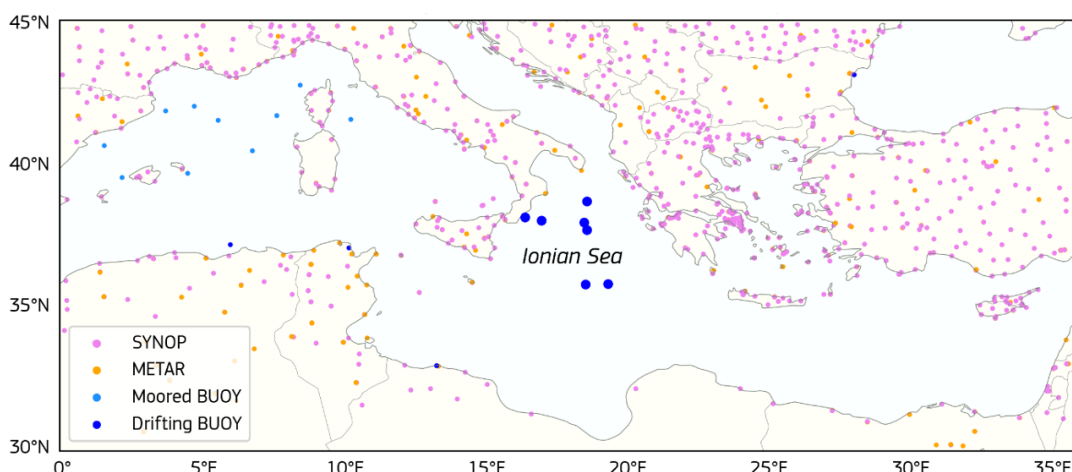
presentations about the current observation network in the Mediterranean, recent extreme events, E-SurfMar's role in coordinating European efforts to maintain and enhance marine surface observation networks, the Global Drifter Program (GDP; <https://gdp.ucsd.edu/ldl/global-drifter-program/>), and on the benefits to forecasts of sea-level pressure observations from drifting buoys. There was broad agreement on the necessity to increase the observation coverage in the Mediterranean and there were discussions around opportunities to make this possible.

During September, seven buoys were released as part of a new project named the Mediterranean Extreme Events Experiment (M3E), involving the Istituto Nazionale di Oceanografia e di Geofisica Sperimentale, Foundation Euro Mediterranean Center on Climate Change, E-SurfMar and Agenzia Italia Meteo. This included five buoys in the Ionian Sea from the research vessel Laura Bassi and two buoys in the open Ionian Sea by commercial shipping coordinated by E-SurfMar. Additional buoys will be deployed in October in the same area.

The buoys launched were Surface Velocity Program Barometer drifters from the GDP (<https://gdp.ucsd.edu/ldl/svpb/>).

Potential for more skilful forecasts

The sea-level pressure observations from M3E buoys are available to all weather services, which brings benefits to the ECMWF Integrated Forecasting System and other modelling systems by providing more accurate initial conditions and therefore potential improvements to short- and medium-range forecasts in countries surrounding the Mediterranean. This deployment is timely with the forthcoming winter season and associated storm activity. It also forms part of a unique opportunity in January and February 2026 when observational campaigns, part of the Global Atmospheric River Reconnaissance Program in the Northern Hemisphere, will run, with the aim to investigate whether adding extra in-situ observations in the North Pacific and North Atlantic Oceans may increase weather forecast skill, both at sea and over land.



Surface pressure observations. The map shows surface pressure observations, excluding those from ships, in the Mediterranean on 14 September 2025, 00 UTC. The large dark blue markers refer to the seven newly deployed drifting buoys in the Ionian Sea and central Mediterranean.

AI takes CEMS flood forecasting into a new era

Ervin Zsoter, Matthieu Chevallier, Christel Prudhomme and Karen O'Regan

The Copernicus Emergency Management Service (CEMS) has taken an important step forward in its operational flood forecasting capabilities. Since 10 September 2025, with the releases of European Flood Awareness System (EFAS) version 5.5 and Global Flood Awareness System (GloFAS) version 4.4, both flood forecasting systems now incorporate forecasts from ECMWF's Artificial Intelligence Forecasting System (AIFS) Single model.

The inclusion of AIFS in EFAS and GloFAS marks a milestone in the operational use of artificial intelligence (AI) for hydrometeorological applications. In EFAS, AIFS complements the existing meteorological forecast inputs (the IFS ENS and COSMO-LEPS ensembles and the ICON deterministic forecast) within the multi-model decision-making workflow. In GloFAS, it represents the first step toward a multi-model forecasting system, which is currently based solely on IFS ENS.

Why was AIFS introduced?

Multi-model advantages: The inclusion of AIFS Single in EFAS and GloFAS strengthens the multi-model approach of both flood forecasting systems. It increases the diversity of meteorological forecast inputs and opens the door for future AI model additions, such as the ensemble system of AIFS ENS, which became operational in July 2025.

Alignment with ECMWF developments: With the last two IFS cycles and IFS ENS upgrade to 9 km resolution, the high-resolution deterministic forecast (HRES), a key component of EFAS, has become redundant with the unperturbed member (Control, IFS CF) of the ensemble. In EFAS, AIFS Single has replaced HRES. For now, it inherits the HRES's forecast-skill-based weights in the flood warning workflow, with plans to recompute the weights of the different forecast inputs once a sufficiently long AIFS Single forecast period becomes available.

Competitive accuracy: Evaluation exercises show that AIFS often delivers higher forecast skill than the

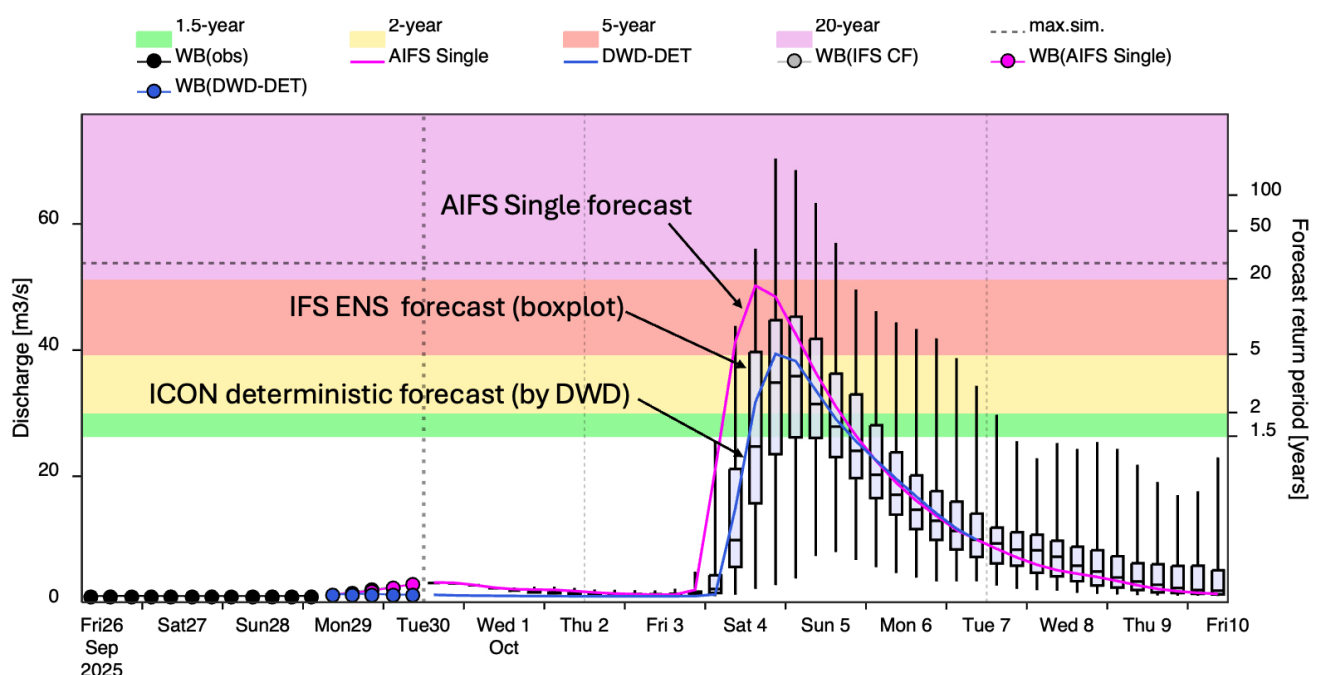
corresponding IFS CF across a range of variables and lead times. For precipitation, the main advantage of AIFS Single is in the medium range, while extreme events benefit less, mainly due to the currently lower resolution of AIFS Single (28 km vs 9 km). Further analysis will inevitably be necessary to fully understand the performance and added value of AI models in the multi-model context of the CEMS-Flood systems.

Operational innovation: By introducing AI into daily operations, EFAS and GloFAS combine scientific robustness with the speed and scalability of machine learning.

Future-readiness: The adoption of AIFS reflects a strategic shift toward hybrid forecasting systems that combine the strengths of physics-based and AI-based approaches.

What does this mean for EFAS and GloFAS users?

For users of EFAS and GloFAS, the integration of AIFS Single means flood forecasts will now deliver enhanced multi-model experience by including both physics-based and data-driven



New discharge hydrograph. Example of a new discharge hydrograph, released as part of EFAS version 5.5 with AIFS Single, for the midday forecast of 30 September on the river Skien in southern Norway.

methods. This translates into richer and more complementary information for decision makers, humanitarian responders and water managers – critical in situations where every possible new forecast scenario might make a difference.

The move also underscores a broader transformation underway within Copernicus and ECMWF: embracing artificial intelligence as a trusted component of operational Earth

system forecasting. While traditional models will likely continue to provide the scientific backbone and necessary training datasets, AIFS and its integration into CEMS-Flood demonstrates the power of AI to strengthen and potentially revolutionise resilience and preparedness in the face of increasing flood risks worldwide.

With AIFS now fully operational in EFAS and GloFAS as of 10 September

2025, CEMS has entered a new era of innovation in flood forecasting.

Feedback from EFAS and GloFAS users about the new AI-enriched CEMS-Flood systems will be crucial and much welcome in the future for our quest to improve flood forecasting on the European and global scales.

Anemoi training-ready version of ERA5 now open to all

Matthew Chantry, Baudouin Raoult and Carlo Buontempo

ERA5 is by far one of the most popular products of the Copernicus Climate Change Service, a programme which ECMWF has implemented on behalf of the European Commission since its introduction in 2018. In recent years, one of the most prominent examples of the use of ERA5 has been in machine learning, particularly in training data-driven models for weather forecasting. ERA5 has been key to a series of high-profile papers that showcased the ability to build state-of-the-art forecasting systems training from this dataset alone. This body of work inspired ECMWF to create the Artificial Intelligence Forecasting System (AIFS), its family of data-driven forecasting systems, which became the first operational models of this kind earlier this year. Both the deterministic and ensemble AIFS systems use ERA5 in the first stage of training.

Working with its Member States, ECMWF has created Anemoi, a framework for training data-driven forecasting models at both global and local scales. Anemoi is used by ECMWF to train and run the AIFS, and by many other partners across Europe to develop their own data-driven forecasting systems. Part of the Anemoi ecosystem is the Anemoi datasets package, which transforms raw meteorological data sources into Zarr datasets – an open-source format optimised for efficient training. Until now, anyone wishing to train a model

with Anemoi first had to build a training dataset.

ECMWF has now released the first Anemoi version of the Copernicus ERA5 dataset, spanning 1979 to 2023 and openly accessible to all users, with a highly permissive licence (CC-BY-4.0). This dataset, hosted on ECMWF infrastructure, is provided on a grid with approximately 1 degree resolution. Directly derived from ERA5, it has been made available to accelerate the engagement with Anemoi for researchers to train their own data-driven forecasting systems. This Anemoi view of a subset of ERA5 aims to complement the broader

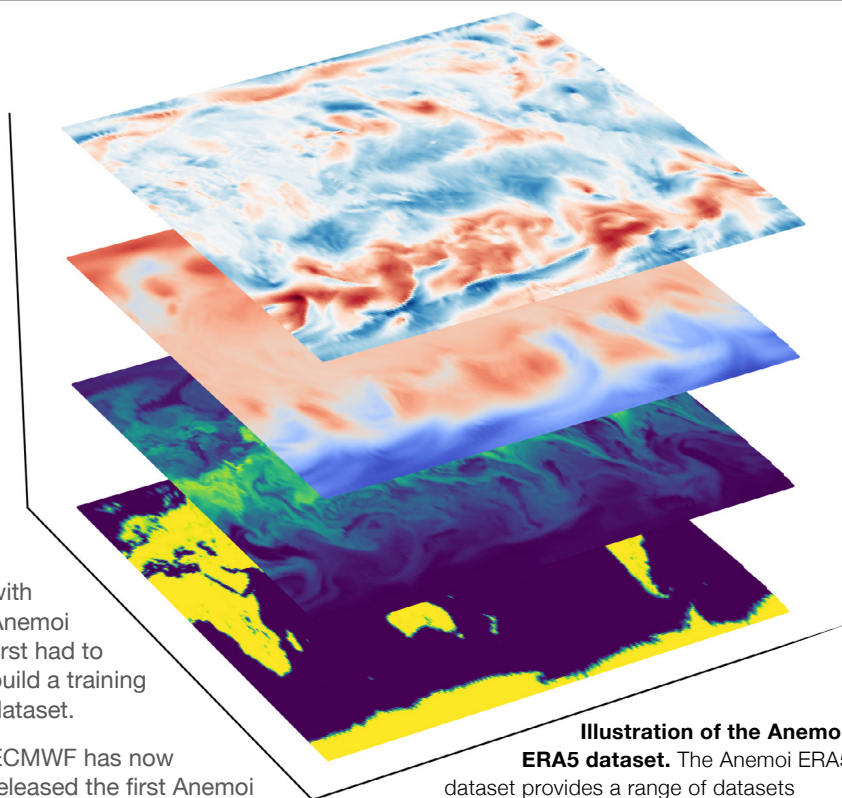


Illustration of the Anemoi ERA5 dataset. The Anemoi ERA5

dataset provides a range of datasets stacked together for efficient reading during training of machine learning models.

access to the full dataset through the Climate Data Store.

Once downloaded, data-driven models can be quickly trained using this dataset, provided users have suitable hardware. For this first release, a lower-resolution version of ERA5 was chosen. While ERA5 is natively produced on a grid of

approximately 0.25 degrees, the coarser grid of the Anemoi version allows faster downloads and more efficient training of experimental systems. This approach intends to help engage an even wider community in this rapidly evolving field, which is now powering operational forecasting systems.

What's next

It is hoped that the community finds this a useful source for exploring data-driven forecasting. Activity will be monitored to shape further expansions. Depending on uptake, further datasets of this type may be released, including higher-resolution

versions, Anemoi versions of ECMWF's operational analysis – designed for fine-tuning data-driven models for live initialisation – and Anemoi versions of the future ERA6. As other Zarr views of ERA5 already exist, ECMWF will also explore ways of coordinating these derived datasets to maintain consistency.

The **Anemoi-ERA5 O96 dataset** provides data in a convenient Zarr format, optimised for efficient training of data-driven forecasting systems. Comprised of roughly 0.5 TB of data across more than 65,000 files, it offers a rich suite of atmospheric variables commonly used in data-driven forecasting. These include six atmospheric variables on 13 pressure levels, and 23 single-level variables such as near surface winds, temperatures and precipitation.

How to access the dataset

Access is streamlined through the anemoi-datasets Python package. To retrieve the dataset:

- `pip install "anemoi-datasets>=0.5.22"`
`anemoi-datasets copy \`
- `url https://data.ecmwf.int/anemoi-datasets/era5-o96-1979-2023-6h-v8.zarr \`
- `target era5-o96-1979-2023-6h-v8.zarr`

Further details on use and the full list of available variables can be found at

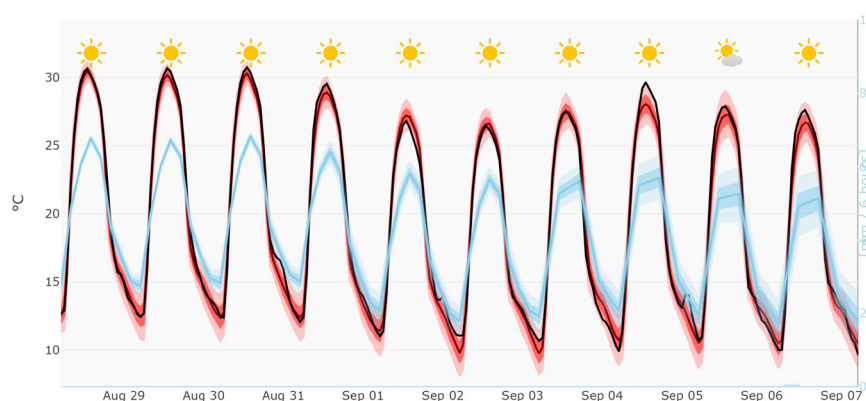
<https://anemoi.readthedocs.io/projects/training/en/latest/user-guide/download-era5-o96.html>.

Low-cost weather stations improve weather services in Tajikistan

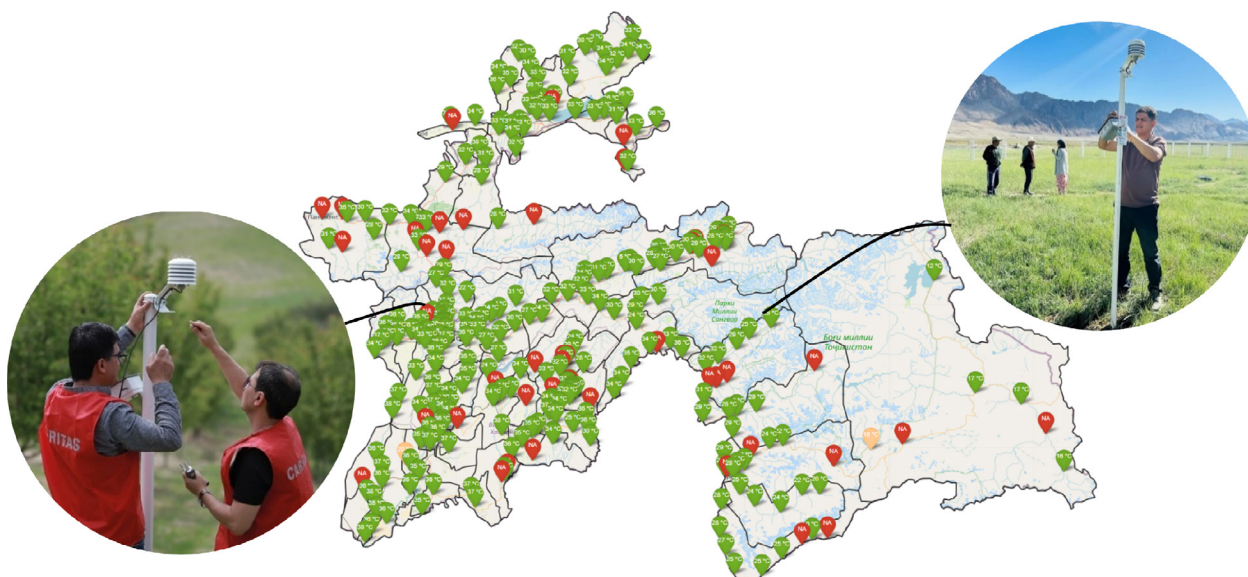
Omar Bellprat, Christoph Spirig (both Federal Office of Meteorology and Climatology MeteoSwiss), Sunatullo Pirov, Jamila Baidullaeva (both Agency for Hydrometeorology under the Committee for Environmental Protection under the Government of the Republic of Tajikistan), Boris Orłowsky, Shinan Kassam, Afzalsho Nasibov, Safarali Yatimov, Nemat Rahmatov (all Caritas Switzerland), Volkan Firat, Cristina Prates, Umberto Modigliani (all ECMWF)

Tajikistan faces severe climatic and geographic challenges. With less than 10% of its territory suitable for irrigated agriculture, food security remains a persistent concern. Land degradation caused by deforestation and overgrazing further weakens ecosystems, while floods and landslides regularly threaten lives and assets—particularly in mountainous areas. Rural communities are highly vulnerable to these hazards, as well as to changing weather that directly affect their agriculture-based livelihoods, health and overall safety.

Despite this vulnerability, accurate weather forecasting, agronomic decision support and early warning systems remain limited. The country's complex topography exacerbates this



A post-processed local temperature forecast. Issued on 27 August 2025 for Romit, Tajikistan, this post-processed local temperature forecast combines the local observation data (black) with the global IFS forecast at 11 km (blue). Post-processed forecasts (red) have a low bias, higher temporal resolution and improved daily variability and ensemble spread.



A map of the new stations in Tajikistan. Tajik Hydromet and Caritas Switzerland have deployed around 320 stations measuring basic parameters such as temperature and air pressure (Sensirion SHT30), as well as other meteorological parameters at 30 measurement sites (Campbell ClimaVUE50). The map shows running stations (green), stations where delivery is behind by two hours (orange) and stations where no data were submitted in the last two days (red).

challenge, requiring a dense observation network to capture local climatic conditions, yet Tajikistan's Hydrometeorological Service (Tajik Hydromet) has long been constrained by scarce resources. As a result, it must largely rely on sparse observations and global forecasting products.

To address this gap, Caritas Switzerland initiated a project in 2021, jointly funded with the Swiss Agency for Development and Cooperation, including a peer-to-peer partnership between Tajik Hydromet and MeteoSwiss. Running until 2025, the project strengthens local forecasting capacity and feeds Tajik observation data into the ECMWF assimilation, targeting improvements to both local and global forecasts.

Low-cost stations to provide local forecasts and services

The project prioritised the development of low-cost, easy-to-maintain weather stations that could be managed by Tajikistan Hydromet. Previous experience had shown that high-end imported equipment was often unsustainable due to costly maintenance. By contrast, the new stations can be serviced locally since they do not rely on vendor expertise, are built on an open-source design, and yet still rely on proven sensor technology. Their performance has

been validated against MeteoSwiss' surface measurement network stations. Currently, around 320 stations across Tajikistan measure temperature, humidity and air pressure, while around 30 sites also capture precipitation, wind and solar radiation. This dense, locally managed network provides data quality sufficient for substantially improving local forecasting.

Thanks to this expanded observation base, Tajik Hydromet now benefits from downscaled local forecasts generated through a pragmatic processing chain developed by MeteoSwiss. Applying ensemble model output statistics including topographic predictors based on ECMWF's IFS ENS forecasts, the system now provides locally specific temperature forecasts for Tajikistan's varied terrain. The results consistently outperform available benchmarks, including forecasts from private providers, and are shared via a dedicated forecasting dashboard accessible to hydrometeorologists and civil defence authorities. Pilot programmes have demonstrated significant benefits such as optimised planting schedules, improved irrigation efficiency and timely warnings for extreme weather events.

Use of the data at ECMWF

Thanks to ECMWF's recent work to acquire and use additional surface

observations (<https://www.ecmwf.int/en/newsletter/176/news/increased-use-surface-observations>), it has become possible to incorporate new SYNOP data from Tajikistan. Once the new stations were made available to 4D-Var through the acquisition system, the observation quality was monitored and assessed using statistics of their departures from short-range forecasts, known as the 'background'. When a station's data meet quality standards, it is added to a list of stations approved for assimilation during the monthly data selection procedure.

ECMWF has gradually incorporated more Tajik stations. Currently, 4D-Var assimilates surface pressure and 2-metre temperature observations from about 17% of the 'low-cost' stations, while the land surface assimilation system (LDAS) assimilates 2-metre temperature from around 50% of the stations. However, quality is not the only criterion for assimilation. Factors such as redundancy or significant elevation differences between the station and the corresponding model grid cell can also lead to exclusion.

Enhancing observational coverage in a data-sparse and heterogeneous region like Tajikistan makes these new stations exceptionally valuable for assimilation, as they significantly improve the accuracy of initial conditions for numerical weather prediction.

Verification of global and regional NWP models over South America

Estíbaliz Gascón (ECMWF) and Cynthia Matsudo (SMN Argentina)

South America has long been underrepresented in global numerical weather prediction verification, leaving a gap in understanding forecast performance over the continent.

To address this, a pilot project was launched in early 2024 by the Working Group on Numerical Experimentation (WGNE) and the Joint Working Group on Forecast Verification Research (JWGFVR), in response to the UN Early Warnings for All initiative. Led by Argentina's National Meteorological Service (SMN) and ECMWF, the pilot evaluates global and regional forecast performance over South America. This article summarises the main results, including statistical verification of ECMWF's Integrated Forecasting System (IFS), comparisons with other global and limited-area models, and

case studies of three extreme weather events in Argentina: a destructive convective storm, strong Zonda winds and a prolonged heat wave.

General verification results

Over South America, statistical verification showed positive IFS performance. Upper-air results demonstrated skill comparable to Europe, an unexpected outcome given the Southern Hemisphere's unfavourable land-ocean distribution and sparse upper-air observations.

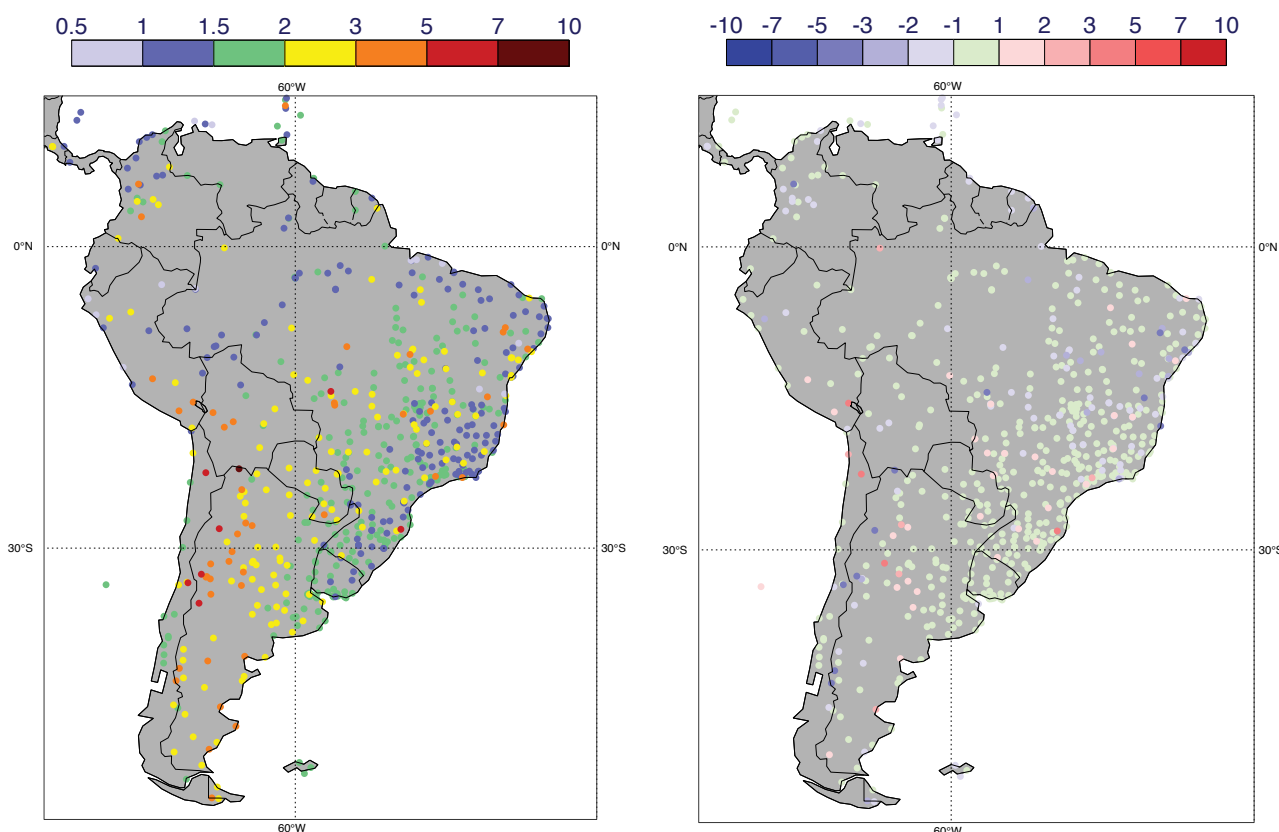
Surface verification indicated generally low bias across most of Argentina. The model performed particularly well in the Pampas and along the Atlantic coast. More challenging conditions were found over the Amazon, where

complex land-atmosphere interactions and dense vegetation make modelling difficult, and in the Andes, where steep topography is difficult to represent. These features are illustrated, for example, in the 2-metre dew point temperature station verification maps.

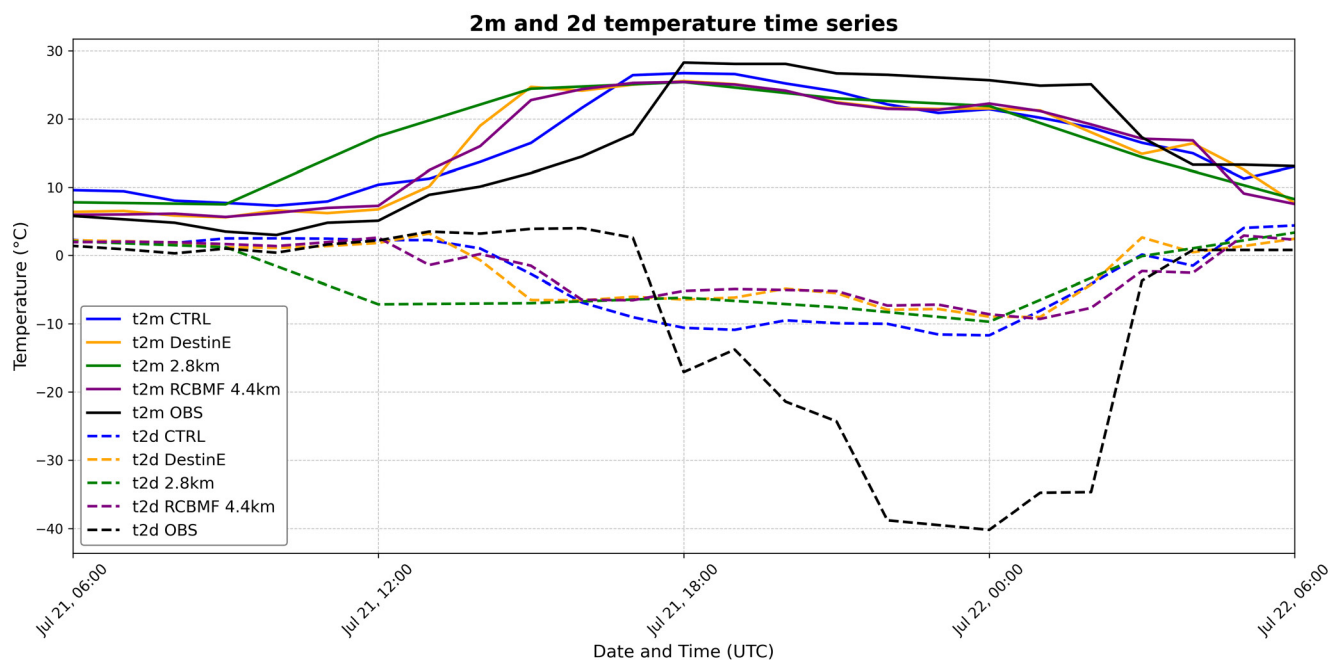
Inter-model comparisons showed the IFS performing competitively with the GFS, ICON, CMC and UKMO models, and achieving skill comparable to Argentina's operational WRF system, which is GFS-coupled, for most meteorological variables.

High-impact weather case studies

Three contrasting extreme weather cases illustrate IFS performance



Error of the dew point forecast. Chart showing error (K) of the T+72-h (ENS control) dew point forecast for the year 2024 measured against SYNOP observations in South America. The left side shows the root mean square error, while the right shows the mean error. Results correspond to the 12 UTC forecast run.



Time series for 2-metre temperature and dew point for a Zonda wind event. Time series for the closest model point to Mendoza Aero station of 2-metre temperature (t2m) and 2-metre dew point temperature (t2d) for a Zonda event. Coloured lines represent forecasts from various ECMWF IFS model configurations: blue corresponds to the operational ENS control forecast at 9 km resolution; yellow to the DestinE forecast at 4.4 km; green to an IFS experiment at 2.8 km resolution; and purple to an IFS experiment at 4.4 km with reduced cloud base mass flux (RCBMF) applied in the deep convective scheme. All the forecast models are initialised on 21 July 2023 at 00 UTC. Observations are shown by black lines.

across different physical mechanisms and predictability challenges.

On 21 July 2023, a Zonda wind event tested the IFS against one of Argentina's most challenging topographic phenomena. The model reproduced downslope winds with high skill, matching or exceeding the WRF. Enhanced IFS experiments with finer resolution and an improved convection scheme showed little benefit over the ENS control, except for some improvement in 10-metre wind gusts. All models, however, struggled to capture the extremely low surface humidity, with 2-metre dew points reaching -40°C .

From 16 to 17 December 2023 in northeastern Argentina, a convective windstorm highlighted the dual challenge of predicting synoptic evolution and extreme surface winds. CAPE-shear Extreme Forecast Index (EFI) values signalled severe potential

up to six days ahead, but the IFS was unable to resolve damaging gusts, a limitation of scale and resolution that was overcome by SMN's higher-resolution model.

In January 2024, a prolonged heatwave in central Argentina assessed predictability of performance from medium-range to sub-seasonal scales. IFS ensemble forecasts captured its temporal and spatial evolution with good skill.

Future collaboration

This pilot project is the first documented effort to assess IFS operational performance over South America and improve severe weather prediction across forecasting systems. A key outcome is a comprehensive Technical Memorandum (<https://www.ecmwf.int/en/elibrary/81664-verification-global-and-regional-nwp-models-over-south-america>)

detailing methodology, systematic verification and high-impact case studies. Future work will explore ensemble and machine-learning-based forecasts, such as those from the Artificial Intelligence Forecasting System (AIFS) and provide more detailed verification of extreme events. A journal article on Zonda predictability using different models and products is also in preparation. From 2026, South America will join the WMO WIPPS standardised verification score exchange (Manual No. 485, <https://library.wmo.int/records/item/35703-manual-on-the-global-data-processing-and-forecasting-system>), strengthening collaboration with global numerical weather prediction centres and supporting the Early Warnings for All initiative. This pilot may also serve as a blueprint for similar efforts across other regions of the world.

A new index to provide early alerts for extreme precipitation

Jessica Keune, Christopher Barnard, Fredrik Wetterhall, Francesca Di Giuseppe

In the framework of the EU-funded project CENTAUR, which aims to bring innovation to several Copernicus services, ECMWF has developed an innovative Extreme Precipitation Index (EPIX). This new index is designed to support the Copernicus Emergency Management Service (CEMS) in guiding satellite mapping during natural disasters, providing location-specific, unbiased evaluations of event rarity and severity using return periods. The proposed extreme precipitation forecasts were recently among the finalists for the prestigious Harry Otten Prize for innovative ideas in meteorology at the European Meteorological Society annual meeting in Ljubljana, Slovenia.

The challenge of forecasting extreme precipitation

Predicting extreme precipitation remains a significant challenge in weather forecasting. Physical numerical models are typically calibrated to represent mean conditions, making rare and intense events difficult to capture. Higher-resolution simulations, such as those developed under the EU Destination Earth initiative, can improve

forecasts of intense precipitation but are costly to run. Next-generation AI-based forecasting systems could also enhance predictions if trained on extreme events, but the scarcity of such events poses a challenge due to their lack of representation in training datasets.

EPIX offers a practical solution for pre-alert purposes. Instead of predicting exact rainfall amounts – which are essential for downstream applications such as hydrology, fire, or drought monitoring – the index identifies locations where extreme precipitation is likely to occur, without specifying precise quantities.

How EPIX works

The index is built on three pillars:

1. Transforming precipitation into return periods to assess rarity.
2. Evaluating spatial coherence of return periods to determine the event's extent.
3. Measuring temporal persistence to gauge severity.

By condensing this information into a single index with three warning levels, EPIX enables authorities to prioritise regions and pre-task satellites for rapid

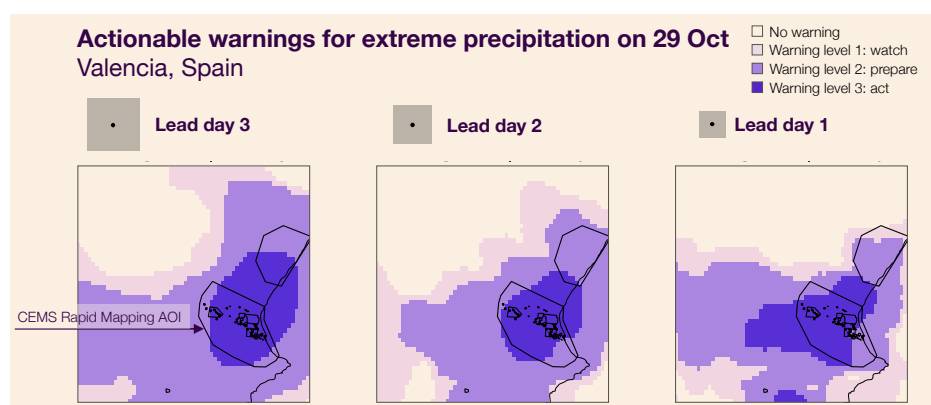
mapping, providing geospatial intelligence for rescue operations on the ground. Its simplicity and compatibility with existing forecasting systems, without significant computational overhead, have generated widespread interest amongst the community.

From innovation to uptake

Although the team did not win the Harry Otten Prize, being amongst the three finalists highlights the innovation and relevance of EPIX in operational meteorology.

Next steps for EPIX include full automation for multiple cities within the CENTAUR project network as part of the demonstration phase. The index is also being tested by the European Response Coordination Centre as a potential new product, supporting the European Crisis Management Laboratory of the Joint Research Centre in efficiently running the CEMS mapping acquisition system.

With its combination of practicality, scientific rigour and operational readiness, EPIX is set to become a valuable tool for emergency management, helping authorities respond more effectively to extreme precipitation events across Europe.



EPIX forecast for extreme precipitation in Valencia in October 2024. On 29 October 2024, Valencia experienced over 600 mm of precipitation in a single day, prompting activation of a CEMS mapping acquisition. The area of interest was selected based on ground reports and numerical weather prediction. EPIX identified the event with a Level 3 warning at least three days in advance and provided sufficient lead time to pre-position the required SAR satellites used for urban flood detection. The Valencia event, with estimated damages in the hundreds of billions of euros, represents the costliest extreme precipitation event in Europe on record. (<https://www.ecmwf.int/en/newsletter/183/news/extreme-precipitation-spains-valencia-region>)

Acknowledgment

The European Union's Horizon Europe research and innovation programme, under grant agreement No. 101082720 – CENTAUR, funded this research. Views and opinions expressed are however those of the authors only and do not necessarily reflect those of the European Union or the Commission. Neither the European Union nor the granting authority can be held responsible for them.

Extreme wildfires in summer 2025

Mark Parrington, Joe McNorton

During the summer of 2025, Europe experienced its worst year of the past two decades for wildfires in terms of area burned, and total emissions of carbon and other smoke pollutants. According to estimated biomass burning emissions from the Copernicus Atmosphere Monitoring Service (CAMS), implemented by ECMWF for the EU, intense fires in the Iberian Peninsula in mid-August resulted in Europe's highest annual total emissions since the start of systematic monitoring in 2003.

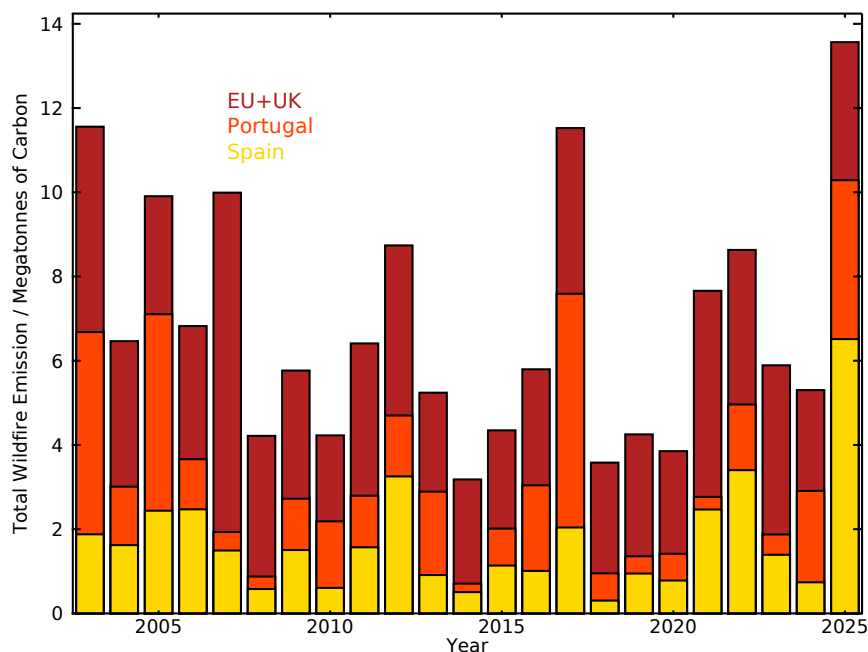
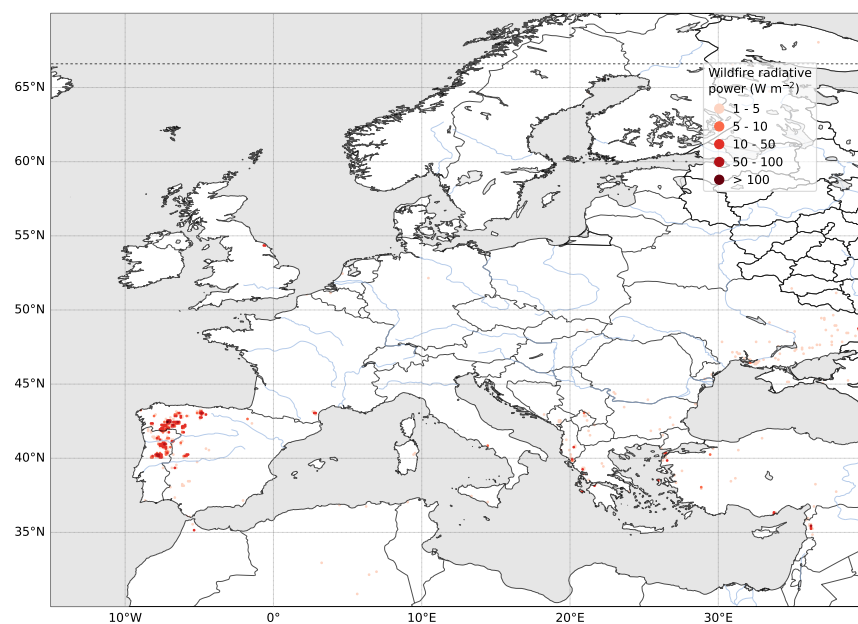
Fire locations and conditions

Fire conditions across Europe during summer 2025 were shaped by a combination of persistent meteorological anomalies and vegetation moisture. In the eastern Mediterranean and southeast Europe (Greece, Türkiye, Cyprus and Syria), below-average rainfall and early heatwaves rapidly dried landscapes and created conditions for an early fire season, with high fire probability indicated by the ECMWF 'SPARKY' Probability of Fire (PoF) model from June onwards. The estimated emissions around the region resulted in some of the highest annual totals in the CAMS dataset, which covers 2003 to present. In contrast, southwestern Europe (and the Iberian Peninsula in particular) experienced a wet winter and spring that promoted extensive vegetation growth. Although the relatively high vegetation water content initially reduced the fire potential, the prolonged heatwaves and rainfall deficits through June and July gradually dried this surplus of fuel.

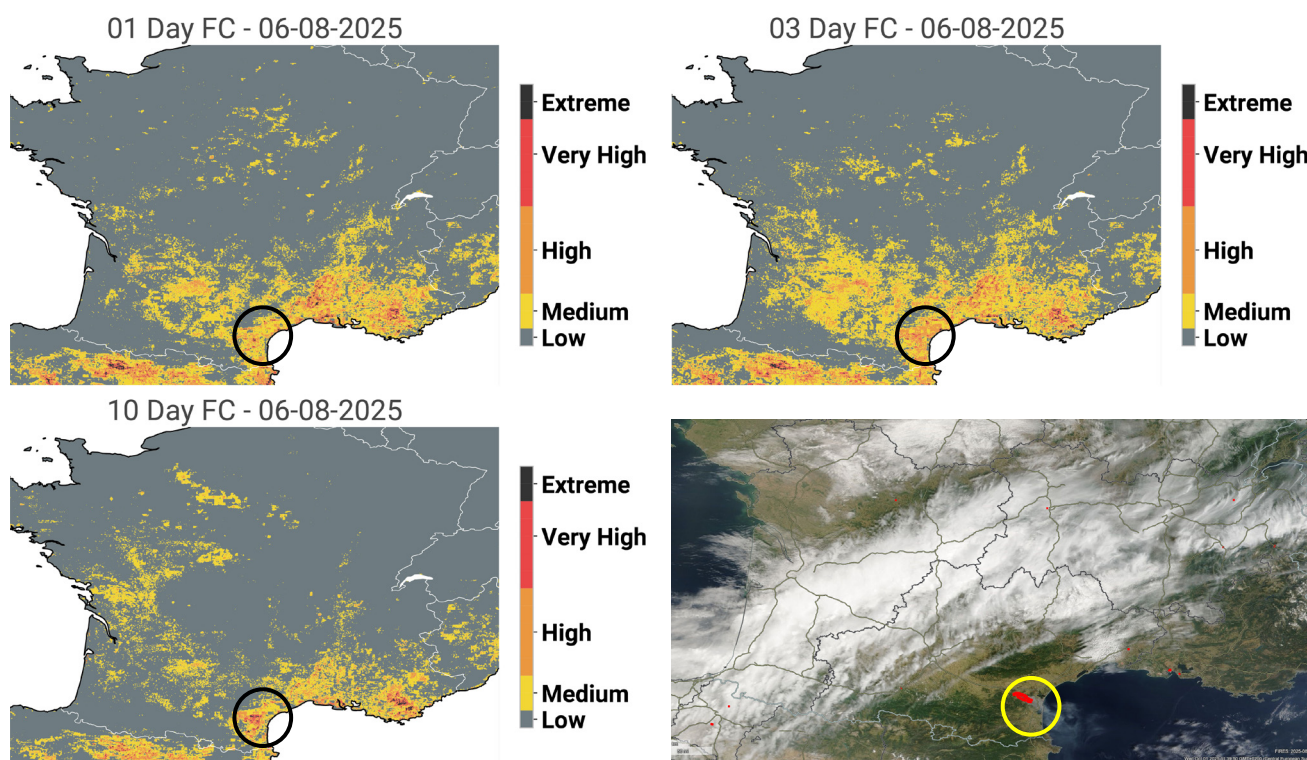
By early August, extreme heat, very low humidity and periods of strong winds created favourable conditions for large and intense fires, particularly in southern France, northern Portugal and Spain. During this period, France experienced its largest recorded fire, with a burned area of about 170 km² in the southwestern Aude department. Despite the significant nature of some of these individual fires, the total estimated emissions for Europe as a whole remained below average.

The picture changed in mid-August, however, as the sequence of spring fuel build-up in Iberia, combined with

persistent high PoF and extreme heatwave conditions across southwestern Europe, provided the ideal conditions for



Fires and associated emissions. (Top) Map of gridded fire locations and Fire Radiative Power for Europe between 1 and 31 August 2025. (Bottom) Bar chart of EU + UK annual total estimated carbon emissions from wildfires from 2003 to 2025 (up to 31 August for 2025) indicating the contributions from fires in Spain (yellow), Portugal (orange) and the rest of the EU and the UK (red). Data from the CAMS Global Fire Assimilation System (GFAS) v1.2, based on Terra and Aqua MODIS active fire observations. Credit: CAMS/ECMWF.



SPARKY-Probability of Fire forecasts and MODIS satellite imagery. SPARKY-Probability of Fire (PoF) 10-, 3- and 1-day forecasts, and MODIS satellite imagery of active fire locations from NASA FIRMS (<https://firms.modaps.eosdis.nasa.gov/map/#d:2025-08-06;@3.9,46.3,7.3z>), for the Ribaute fire in France on 6 August 2025.

fires across the region to rapidly grow in scale and intensity, and persist for several days. Between 10 and 20 August, fires in northern Portugal and the Spanish regions of Galicia, Castilla y León and Extremadura produced approximately three quarters of the 12.5 megatonnes of carbon emissions for all EU countries plus the UK, surpassing the previous highest annual total of 11.8 megatonnes of carbon in 2017.

Air quality impacts and global perspective

Smoke from the fires in Portugal and Spain resulted in increased concentrations of fine-scale particulate matter (PM_{2.5}) and degraded air quality across much of the northwestern region of the Iberian Peninsula for several days through the middle of August. Traces of the smoke were also

transported towards northwestern Europe, which had been experiencing the latest episode of long-range smoke transport from Canadian wildfires a few days before. Wildfires in Canada have been extreme for the third consecutive year, with 2025 having the second-highest annual total emissions, exceeded only by the record set in 2023. Long-range smoke transport across the Atlantic to Europe has been particularly prominent in 2025, with several episodes in June, July and August monitored by CAMS and well observed in different measurements at several European sites.

Why wildfires are forecast and monitored

Wildfires represent a diverse range of impacts across different scales, from risk to human life and infrastructure,

local air quality degradation in downwind regions to long-range effects at both continental and inter-continental scales. Wildfires are driven by rapidly changing weather, slow growing fuels and stochastic ignition sources, making them difficult to anticipate. The SPARKY-PoF system provides real-time 10-day forecasts of the probability of an active fire detection within each 1 km grid cell. Forecasting provides an early-warning capability to support preparedness, risk reduction and response planning. CAMS near real-time monitoring of wildfire emissions around the world and the impacts on atmospheric composition are essential for evaluating the CAMS forecast performance. It also enables applications of CAMS open data on significant episodes which can lead to degraded air quality in near real-time.

The introduction of waves in sea ice

Josh Kousal, Jean Bidlot, James Steer (all ECMWF), Jean Rabault (Norwegian Meteorological Institute)
Malte Müller (Norwegian Meteorological Institute and The University of Oslo).

Over the last few decades, the polar regions have become an increasing focus for the weather and climate

science community, and there is clear evidence that the interactions between waves and sea ice are important

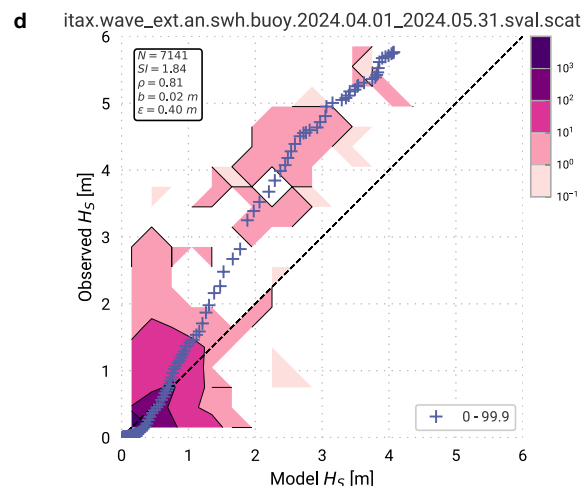
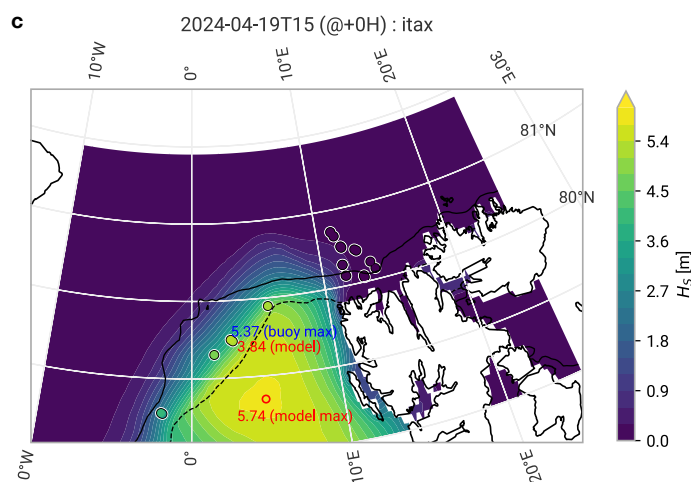
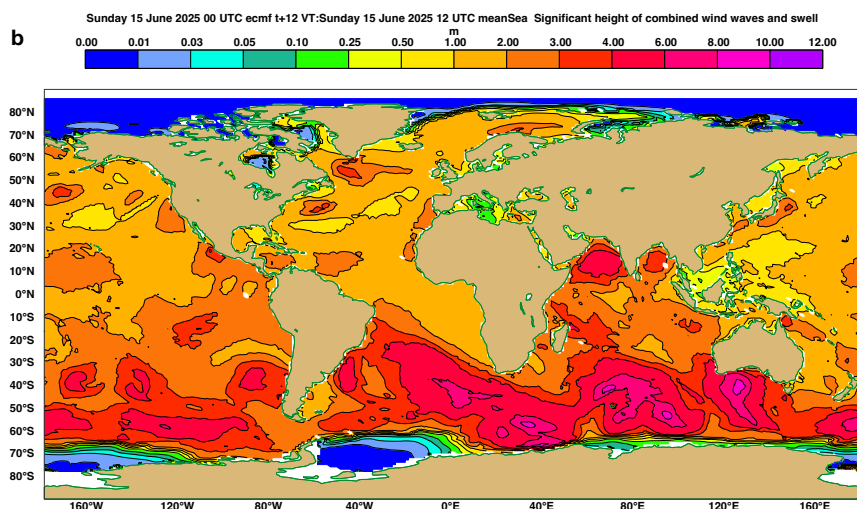
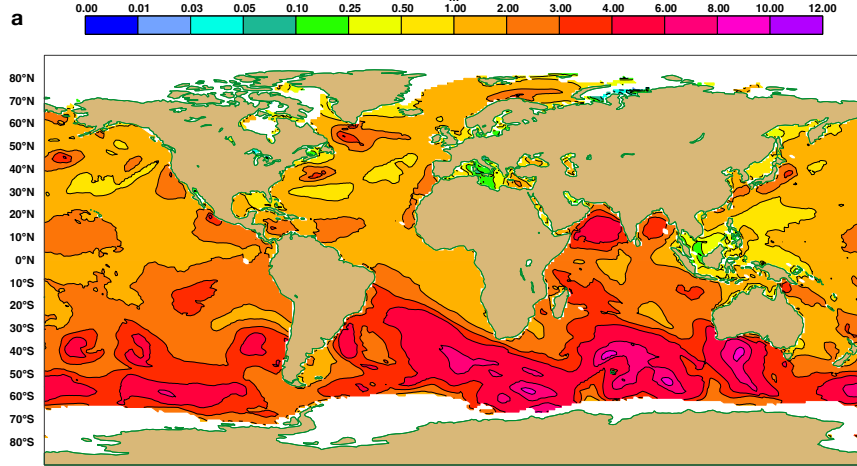
across various time scales.

In the present and past ECMWF operational forecasting systems, wave-sea ice interaction has not been represented. In the ECMWF Ocean Wave Model (ecWAM), waves are simulated only up to 30% sea ice cover (SIC). Beyond this limit, they are instantly attenuated (i.e. set to 0), and most model output variables are masked, thereby providing no wave information in areas with higher levels of ice cover.

In Cycle 50r1, scheduled for operational implementation in early 2026, waves have been introduced into the sea ice. First, the wave model is allowed to operate under all sea ice conditions. To describe the attenuation rate, a state-of-the-art

Significant wave height. Significant wave height (H_S) in Cycle 49r1 (a) and Cycle 50r1 (b). (c) Modeled and observed H_S for the Svalbard Marginal Ice Zone 2024 (SvalMIZ-24) campaign's largest storm, with the buoy location indicated by a black circle. Dashed and solid black lines mark 15% and 85% sea ice concentration (SIC) contours from ORAS6 respectively. (d) Statistical comparison of modeled and observed H_S for the SvalMIZ-24 campaign. Shown is a scatter density plot, with a quantile-quantile comparison up to 99.999 denoted by blue crosses.

Sunday 15 June 2025 00 UTC ecwf t+12 VT: Sunday 15 June 2025 12 UTC meanSea Significant height of combined wind waves and swell



model is used that accounts for ice thickness and wave frequency. With this implementation, consistent wave forecasts across the polar regions can be provided.

With recent advances in hardware and software, wave buoys have reduced in cost. This has enabled the Norwegian Meteorological Institute (Meteorologisk Institutt), which has largely been spearheading this work, to deploy many more buoys in their campaigns. Because each buoy provides only a single observation point, and sea ice is inhomogeneous, many buoys are needed to build a representative picture. Thanks to collaborations with colleagues in Norway, the Cycle 50r1 model can now be tested and verified against such campaign data.

Taking the Svalbard Marginal Ice Zone (MIZ) 2024 (SvalMIZ-24) campaign as an example, to verify the Cycle 50r1 model, a wave model hindcast was run over the campaign period, using atmospheric information from ERA5, and ocean and sea ice information from ORAS6. The model predictions of wave height (H_S) were then compared with those measured by the buoys.

The top two panels of the figure show model H_S for Cycle 49r1 and Cycle 50r1 globally during the SvalMIZ-24 campaign. As waves enter the polar regions in the Cycle 50r1 model, there is a sharp but smooth gradient as they are attenuated by the sea ice. For Cycle 49r1, no wave information is provided for SIC>30%. Focusing on

the SvalMIZ-24 campaign, the bottom left panel shows model and observed H_S for the campaign's most intense storm. Within the MIZ (between the 15% and 85% SIC contours, marked by the solid and dashed contour lines, respectively), the buoys measure waves of up to $H_S = 5.37$ m. The Cycle 50r1 model also shows large waves in this region but is low biased ($H_S = 3.84$ m at this location). In the pack ice north of Svalbard however, (>85% SIC), the Cycle 50r1 model and the buoys agree: the waves have been fully attenuated ($H_S \approx 0$ m).

The bottom right panel shows a statistical verification of the model in the MIZ zone for the campaign: for the bulk of the measurements ($H_S < 2$ m), the model is unbiased with respect to the observations, albeit random errors remain significant. For larger waves ($H_S > 2$ m), the model is low biased compared to the observations. Although there is room for improvement, the Cycle 50r1 model can capture the basic evolution of waves in sea ice. This represents a significant qualitative advancement compared to Cycle 49r1, which is unable to provide wave information in these regions.

The Cycle 50r1 implementation represents a one-way coupling between waves and sea ice (attenuation of waves by sea ice). This implementation, along with the development of the relevant verification infrastructure, lays the foundations for a larger body of work

that is currently underway: the representation of two-way coupled interactions between the waves and sea ice.

Additionally, in Cycle 50r1, refraction by ocean surface currents will be activated, using ocean information from the coupled ocean model NEMO4. Refraction can alter the direction of wave propagation, resulting in wave focusing, meaning waves are larger in some areas and smaller in others, as seen most clearly in the tropics through the increased small scale variability in the contour lines, shown in the top two panels of the figure, due to the strong currents here.

Help shape our wave products

Are you interested in helping shape wave products at ECMWF? If so, get in touch through this QR code or at <https://tinyurl.com/ecmwf-wave-survey>



New observations July – September 2025

The following new observations have been activated in the operational ECMWF assimilation systems during July – September 2025

Observations	Main impact	Activation date
Radiances from the Microwave Radiometer on the Arctic Weather Satellite	Temperature, humidity, dynamics	10 July 2025
Radio occultation bending angles from FY-3E GNOS-2	Temperature and winds in upper troposphere/lower stratosphere	10 July 2025

AIFS ENS becomes operational

Simon Lang, Linus Magnusson

In recent years, machine-learned (ML) weather forecasting systems such as FourCastNet, Pangu-Weather, GraphCast and the Artificial Intelligence Forecasting System (AIFS) have shown that they can produce highly skilful deterministic predictions that match or exceed those from physics-based models. These forecast models learn how to forecast by advancing the atmospheric state from one analysis date to the next during training. When in forecast mode, they run autoregressively – they evolve the atmospheric state forward in time from their own predictions.

However, the first-generation ML models typically tend to produce overly smooth fields, lacking the small-scale features that are observed in reality. This is because they are trained using a mean-squared error (MSE) objective, which can lead to reduced variability in the forecast fields.

Smoothing reduces differences among ensemble members, which decreases the spread, measured by the ensemble standard deviation, and can make the forecast unreliable. In other words, the forecasted probabilities do not match reality.

Probabilistically trained models have now been developed that address these limitations. For example, denoising diffusion-based models that start with random noise and gradually refine it, like GenCast and AIFS-Diffusion, and models trained with a loss based on a proper score, which encourages realistic atmospheric

variability of forecast fields, like AIFS-CRPS. Compared to diffusion-based models, the direct optimisation of proper scores such as the Continuous Ranked Probability Score (CRPS) provides several practical advantages. First, the model can learn how to forecast across many steps. Second, generating ensemble members requires just one model evaluation per forecast step. This makes them potentially orders of magnitude more computationally efficient to run than diffusion-based models that rely on a sampler for forecasting, requiring the model to be called many times for each single forecast step. Tests have also shown that AIFS-CRPS gives more accurate forecasts than diffusion-based models. Due to the advantages demonstrated by AIFS-CRPS, the CRPS-based training approach has been adopted by others, including FourCastNet 3 by NVIDIA and Functional Generative Networks (FGN) by Google DeepMind.

After a testing phase to assess real-time forecast performance, we have now transitioned AIFS-CRPS into an operational system. It is named AIFS ENS to distinguish it from the deterministically trained AIFS Single.

Model description

AIFS ENS has been trained on 38 years of ERA5 reanalysis data (1979–2017) and eight years of data from the Integrated Forecasting System (IFS) operational analyses (2016–2023). Like the AIFS Single, the model uses an encoder-processor-decoder architecture in which the encoder reduces the input to a lower-

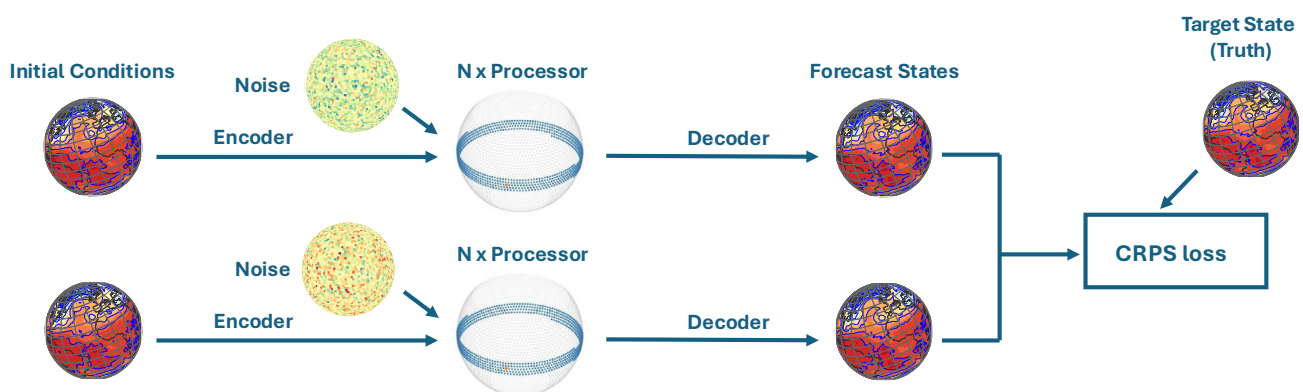


FIGURE 1 AIFS ENS training, showing the encoder-processor-decoder architecture in which the encoder reduces the input to a lower-resolution internal grid, the data are processed, and the decoder projects it back to the output grid. The loss is computed from two ensemble members in training.

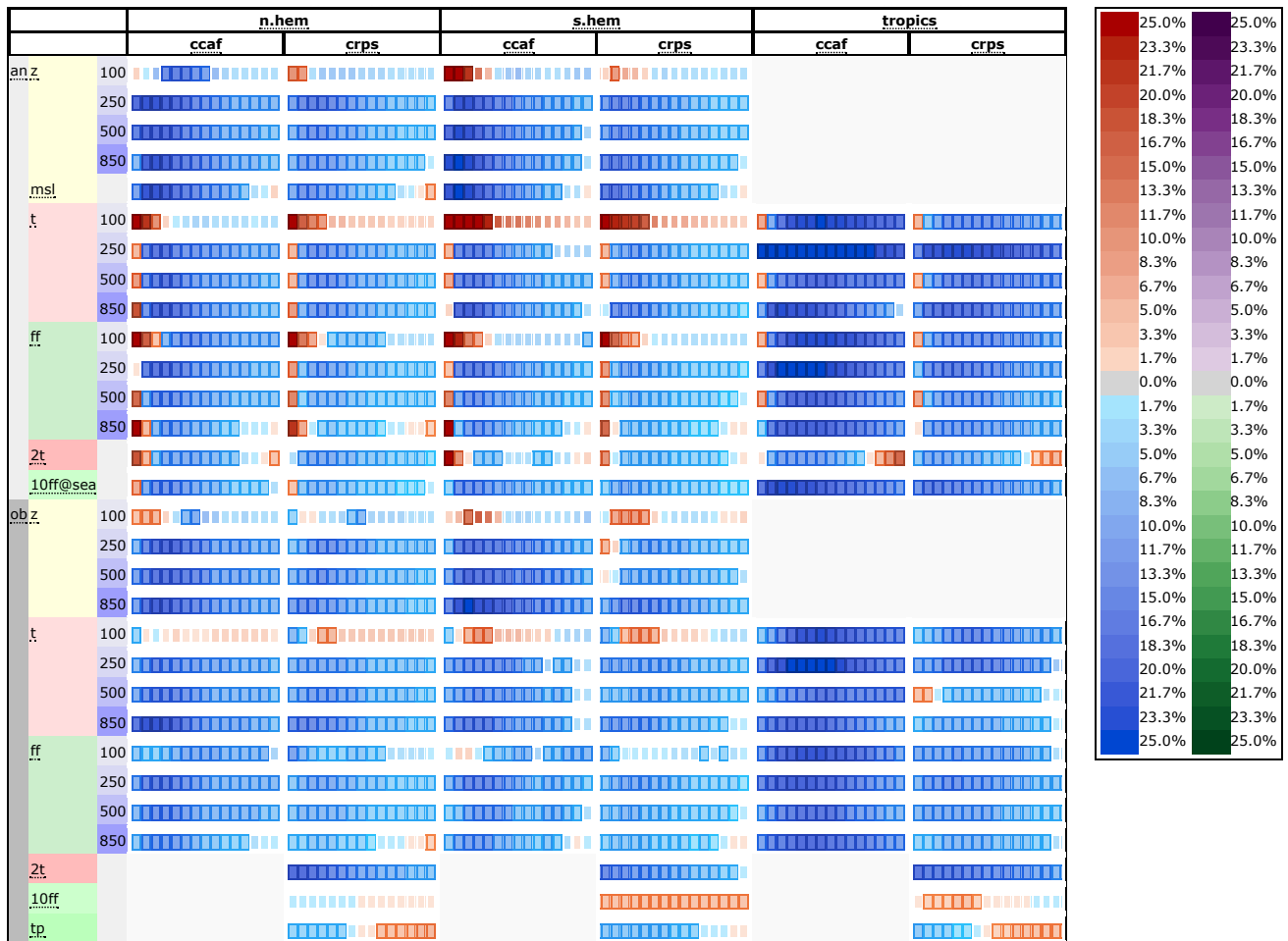


FIGURE 2 Scorecard comparing AIFS ENS with IFS ENS. Blue shading indicates where the AIFS ENS outperforms the IFS ENS and red shading indicates a degradation in forecasting skill.

resolution internal grid, the data go through the processor, and the decoder projects it back to the output grid (Figure 1). The encoder and decoder use transformer-based graph neural networks, while the processor is a transformer with a sliding attention window, which processes information across a latitudinal band. AIFS ENS has a total of 229 million parameters and a spatial resolution of approximately 30 km. Ensemble members are generated by introducing noise within the processor. When generating forecasts, as many members as required can be generated by providing different random seeds to the model. Two ensemble members are used in training.

AIFS ENS currently has 50 perturbed members and one control member. However, unlike the physics-based IFS ENS, where the control member uses unperturbed initial conditions and the forecast model is unperturbed as well, the AIFS ENS control member also starts from unperturbed initial conditions but still includes model-generated variations during the forecast. This means that all AIFS ENS members, including the control, are

stochastic forecasts that represent different outcomes from a learned forecast distribution.

Evaluation of forecast skill

AIFS ENS forecasts have been evaluated against IFS analyses and against radiosonde and SYNOP observations. Figure 2 displays the resulting scorecard, with blue shading indicating where AIFS ENS outperforms the IFS ENS and red shading indicating a degradation in forecasting skill. This scorecard shows forecast improvements reach up to 25% and that AIFS ENS has higher forecast skill for upper-air variables. The skill improvements result from reductions in both bias and random component forecast errors. Degrations, however, are seen for forecasts of conditions higher up in the atmosphere. For example, temperature at 100 hPa shows a degradation when verified against IFS operational analyses and to a lesser degree when verified against radiosonde observations. For early lead times, AIFS ENS forecasts can appear less skilful than IFS ENS forecasts when verified against IFS analyses;

however, this degradation of AIFS ENS compared to IFS ENS is not visible when SYNOP and radiosonde observations are used for verification. In terms of surface variables verified against SYNOP observations, AIFS ENS shows improved scores for 2-metre

temperature for all lead times, and during the first half of the forecast for 24-hour accumulated total precipitation. For 10-metre windspeed, IFS ENS is more skilful than AIFS ENS when verified against SYNOP observations.

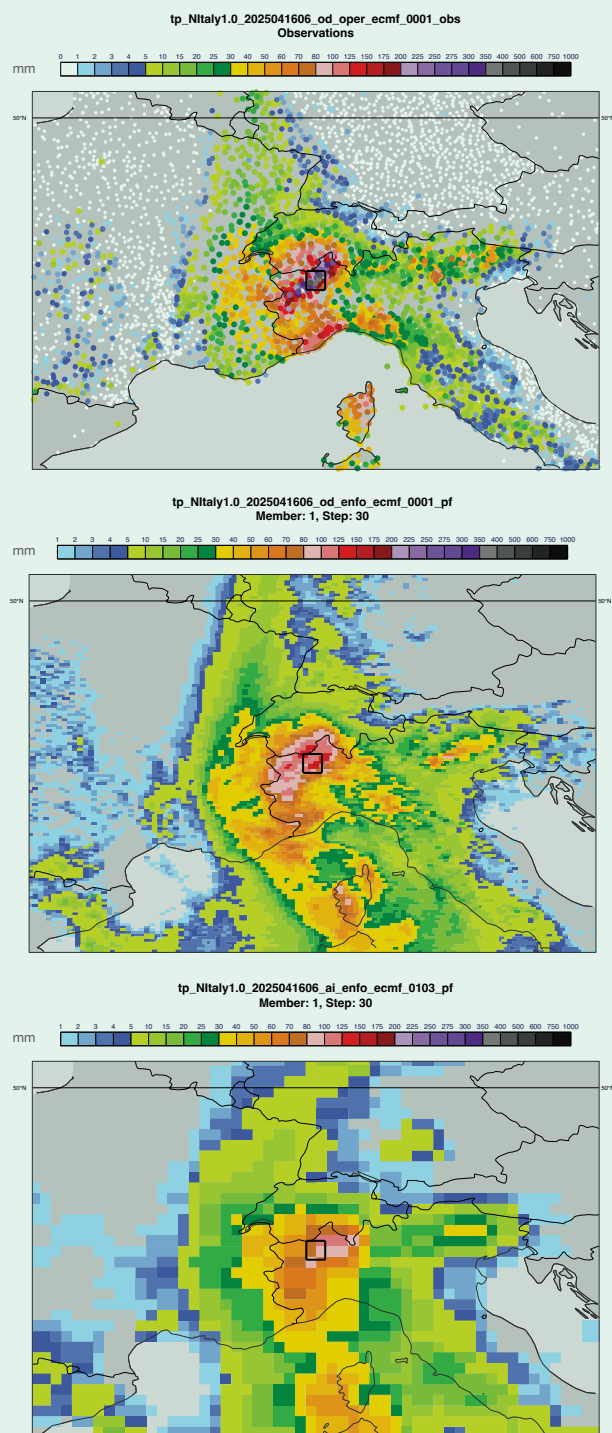


FIGURE 3 24-hour accumulated precipitation, 16 April 06 UTC – 17 April 06 UTC. Observations (top), IFS ENS member 1 (middle) and AIFS ENS member 1 (bottom).

Case study – Storm Hans in the Alps

In April 2025, Storm Hans brought extreme conditions to the southern Alps. High precipitation values, of as much as 446 mm in a 24-hour period, were recorded in northern Italy and southern Switzerland on 16 and 17 April. Figure 3 shows the 24-hour accumulated precipitation values from observations, IFS ENS member 1 and AIFS ENS member 1, of a 54-hour forecast. The perturbed members of both ensemble systems reproduce the overall precipitation pattern, though they underestimate maximum values. The underprediction of AIFS ENS seems more pronounced than in the case of IFS ENS. One likely factor is the resolution of the forecasting systems – approximately 9 km for the IFS compared to approximately 30 km for the AIFS.

Figure 4 shows the time evolution of the predicted 24-hour precipitation values from AIFS ENS and IFS ENS averaged inside the box shown in Figure 3. Both ensemble systems show a similar forecast evolution, again with AIFS ENS more strongly underpredicting the observed values. Nevertheless, both AIFS ENS and IFS ENS gave early indication of the possibility of an extreme event.

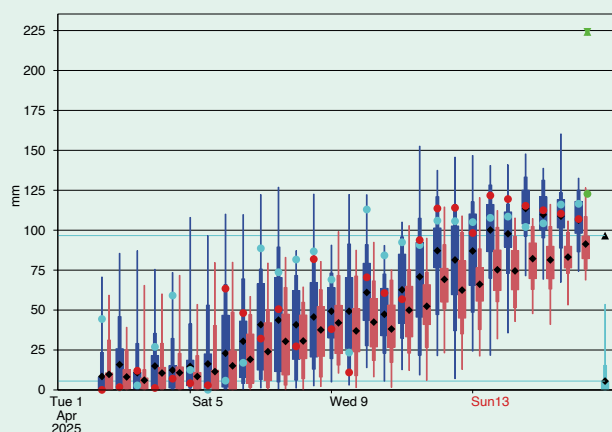


FIGURE 4 24-hour precipitation 16 April 06 UTC – 17 April 06 UTC in a 0.5-degree box in the Italian Alps (see Figure 3). Showing observation (green hourglass), Analysis (green dot), IFS ENS (blue), AIFS ENS (pink), IFS model climate (cyan).

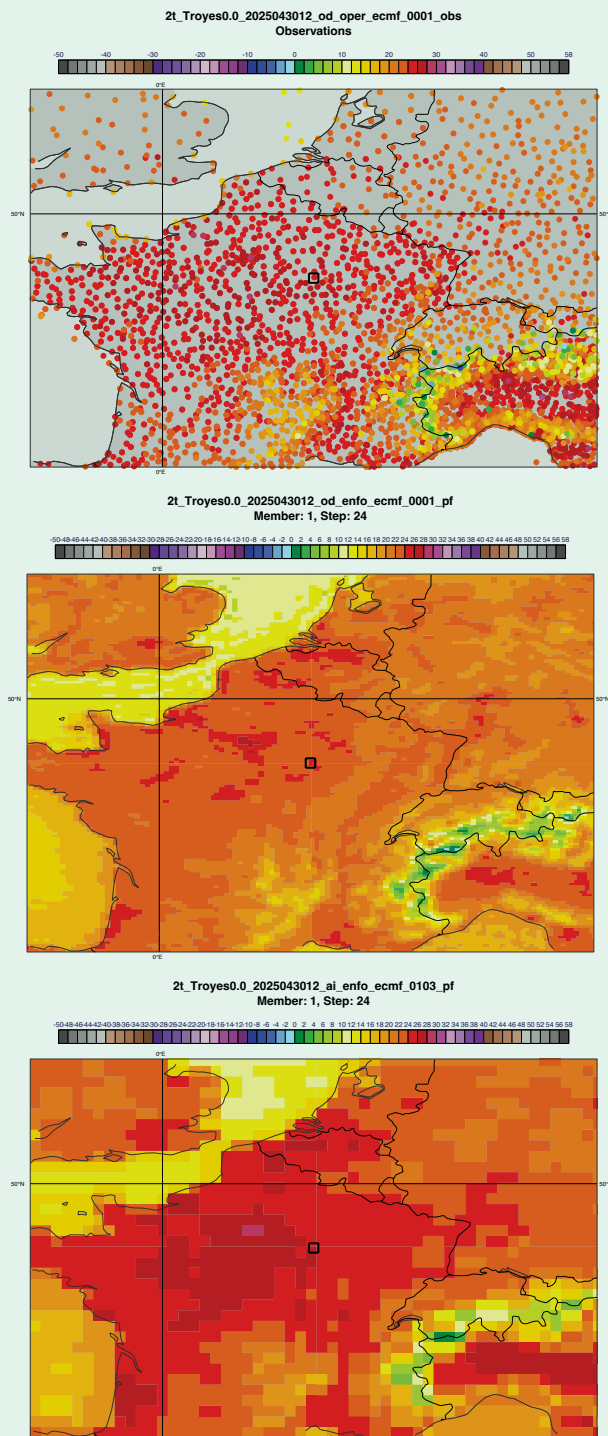


FIGURE 5 Two-metre temperature 30 April 12 UTC, observations (top), 24-hour forecast of IFS ENS member 1 (middle) and AIFS ENS member 1 (bottom).

Case study – heatwave in France

On 30 April 2025, France was struck by a heatwave. Figure 5 shows observations and short-range forecasts from IFS ENS and AIFS ENS member 1, respectively. Even for this short lead time, IFS ENS underestimated the observed temperatures. AIFS ENS, however, predicts temperature values closer to those observed.

The evolution of these forecasts is shown in Figure 6. Initially, both ensembles perform similarly; however, closer to the event, around the 7-day lead time, AIFS ENS starts to predict higher temperature values than IFS ENS. It is being investigated why the IFS ENS underestimated this heatwave and other similar conditions during late spring to early summer 2025.

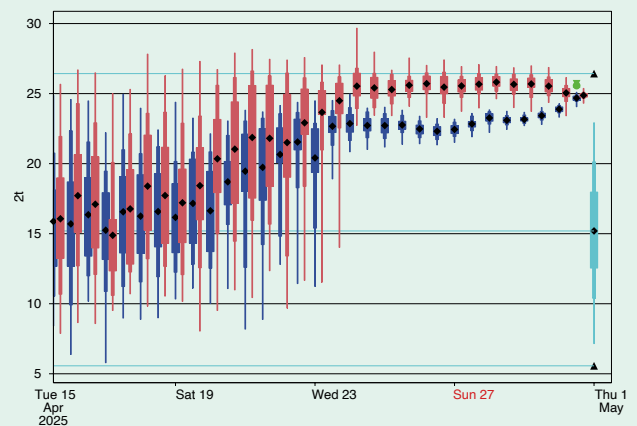


FIGURE 6 Evolution of forecasts for 2-metre temperature on 30 April 2025 at 12 UTC in Troyes, France. Symbols show observation (green hourglass), analysis (green dot), IFS ENS (blue), AIFS ENS (pink) and IFS model climate (cyan).

Limitations

While AIFS ENS shows strong forecast performance, as measured by scores for upper-air and surface conditions, some limitations remain. For example, anomalous values in mean sea level pressure and low-level temperature fields can develop, especially in regions with complex topography such as mountain ranges. Another example is 2-metre temperature forecasts, which can show degradations beyond day seven, with unrealistic cold biases appearing episodically in high-altitude locations and specific regions, including the Red Sea.

The model also exhibits systematic biases in precipitation forecasting, generating spurious trace amounts of rainfall or snowfall (typically less than 0.1 mm per 6-hour period) in arid regions. This issue becomes particularly apparent when examining longer accumulation periods.

Cloud cover forecast, while skilful, displays a noticeably coarser spatial resolution compared with other atmospheric variables, resulting in a blocky appearance. This limitation affects the model's ability to represent fine-scale cloud structures that are important for understanding local weather phenomena.

Finally, AIFS ENS is currently overdispersive for a range of upper-air variables – in other words, the ensemble standard deviation is larger than the root mean squared error of the ensemble mean. It is likely that this is related to the fact that AIFS ENS uses the same initial perturbation as the IFS ensemble. To improve the reliability of the IFS ensemble, singular vector

perturbations are added to the initial conditions. Because AIFS ENS forecast errors are smaller, it might require a different initial perturbation amplitude.

The limitations described are under investigation, with improvements expected in future model cycles.

Conclusion and outlook

AIFS ENS has successfully transitioned from research to operational status, providing highly skilful ensemble forecasts. The CRPS-based training approach enables the generation of probabilistic forecasts with realistic atmospheric variability, suitable for ensemble forecasting. At the same time, models trained this way are computationally efficient, with each ensemble member requiring only one model evaluation per forecast step.

Performance evaluations comparing AIFS ENS to IFS ENS show improvements of up to 25% for upper-air variables and positive impacts for surface variables such as 2-metre temperature and total precipitation.

There remain several limitations to the model, including artefacts in mean sea level pressure, low effective resolution in cloud fields and spurious patterns in accumulated precipitation. Ongoing work aims to address these issues in future model cycles.

The operational implementation of the AIFS ensemble represents a milestone in ECMWF's machine learning journey. Further development will also focus on increasing horizontal and temporal resolution, and incorporating additional Earth system components.

Further reading:

Lang, S., M. Alexe, M.C.A. Clare, C. Roberts, R. Adewoyin, Z.B. Bouallègue et al., 2024: AIFS-CRPS: Ensemble forecasting using a model trained with a loss

function based on the continuous ranked probability score. arXiv preprint arXiv:2412.15832 <https://doi.org/10.48550/arXiv.2412.15832>

Upgrade to IFS Cycle 50r1

Inna Polichtchouk, Sébastien Massart, Zak Kipling

An upgrade to ECMWF's Integrated Forecasting System (IFS) is scheduled for operational implementation in early 2026. IFS Cycle 50r1 introduces a new ocean and sea ice configuration based on the NEMO4-SI³ model (a state-of-the-art modelling framework used for research activities and forecasting services in ocean and climate sciences – Nucleus for European Modelling of the Ocean coupled with the Sea Ice Modelling Integrated Initiative is developed by a European consortium), alongside a new ocean data assimilation system. The level of ocean–atmosphere coupling in the four-dimensional variational (4D-Var) data assimilation system is enhanced by using outer-loop coupling, a method that increases the consistency of the ocean and atmospheric initial conditions. An additional 12-hour window ocean analysis is now running in parallel to the atmospheric analysis. Together, these changes improve the representation of ocean–sea ice–atmosphere interactions. The cycle also revises the treatment of convection with the aim of improving aspects such as inland propagation of convective precipitation. In the stratosphere, reduced vertical diffusion (small-scale mixing of air between different

heights) improves representation of the quasi-biennial oscillation (QBO) of tropical zonal winds between easterly and westerly and of the humidity. The data assimilation will also be able to extract stratospheric humidity information from observations and make use of more 2-metre temperature observations. Cycle upgrades to the ensemble system include scale-selective re-centring in the Ensemble of Data Assimilations (EDA) and a revised Stochastically Perturbed Parametrizations (SPP) scheme, which represents model uncertainty, to reduce excessive 10-metre wind spread. Additional improvements include a new glacier scheme and refined wave–sea ice coupling. These developments result in more realistic coupled forecasts, better use of observations, through both assimilating more data and extracting more information from them, and reduced computational cost.

Key changes to the forecast model

IFS Cycle 50r1 introduces a wide range of improvements to the forecast model, targeting improved physical realism in convection, ocean and sea ice processes, land-surface interactions and stratospheric dynamics. It also addresses

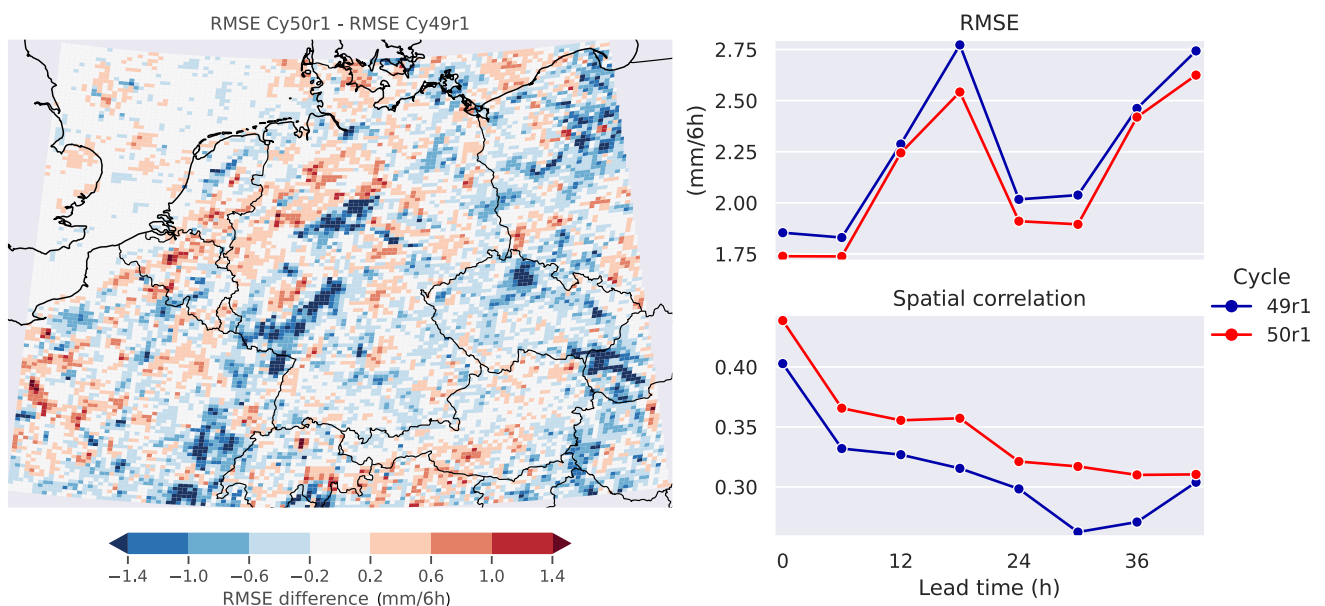


FIGURE 1 Verification of rainfall forecasts against radar observations over Europe. The map shows the differences between Cycle 50r1 and Cycle 49r1 of root mean square error (RMSE) for all forecast lead times combined (blue indicates that 50r1 is improved), while the line plots show RMSE and spatial correlation as a function of lead time, averaged over Europe. Red lines correspond to Cycle 50r1 and blue lines to 49r1. Lower RMSE and higher correlation indicate improved forecast skill. Verification is performed for June 2024. Credit: Llorenç Lledó.

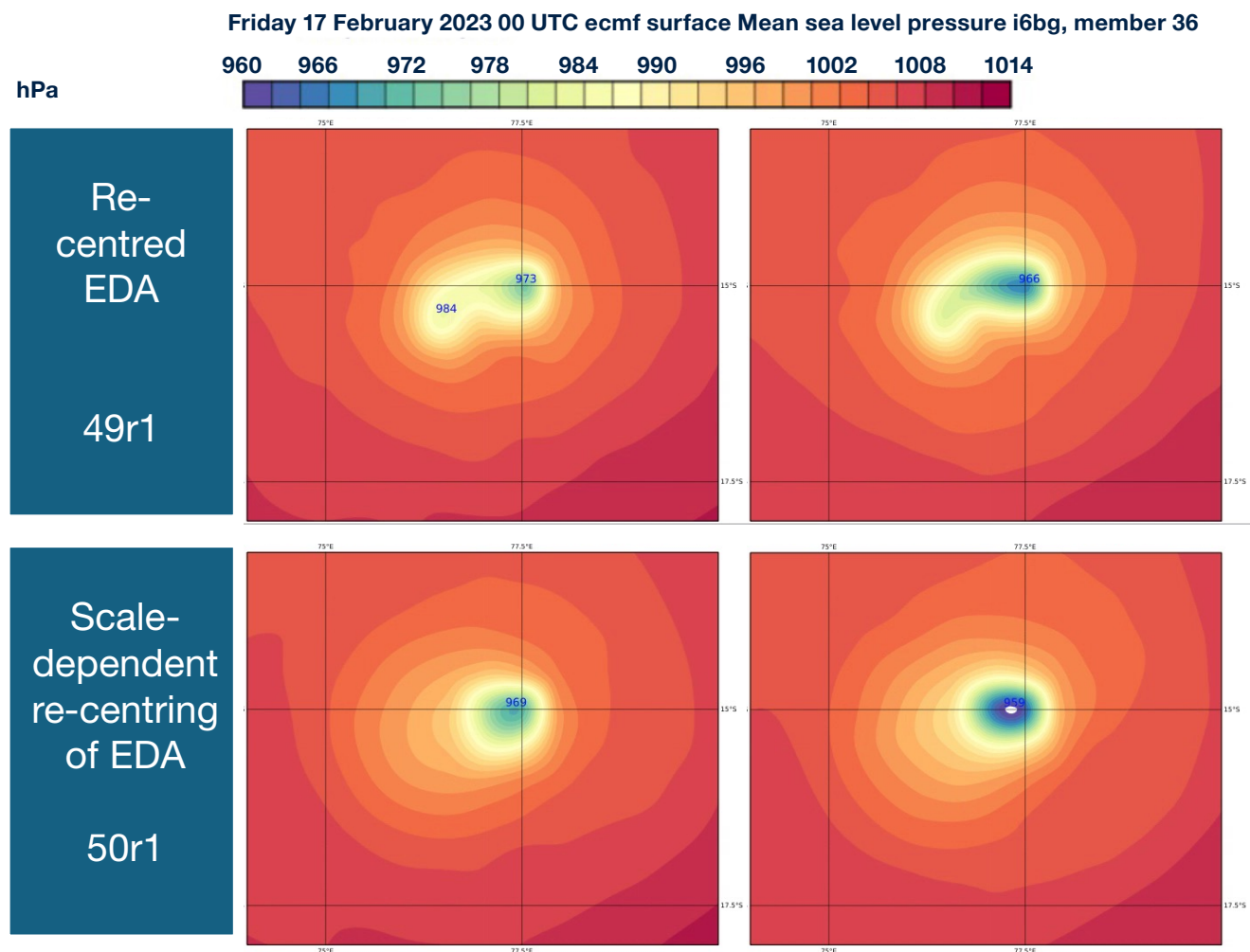


FIGURE 2 Mean sea level pressure at forecast step = 0 h for Tropical Cyclone Freddy on 17 February 2023 at 00 UTC, shown for ENS members 36 and 45. The top panels show results with the old EDA re-centring (Cycle 49r1), while the bottom panels use the new scale-selective EDA re-centring to be introduced in Cycle 50r1. The new method removes the unrealistic 'double centre' feature present in the previous configuration. Credit: Sarah-Jane Lock and Martin Leutbecher.

known forecast issues, such as stationary precipitation, excessive ensemble spread for surface winds and degraded tropical temperature biases.

A key change is a revision of how the model handles deep convection and cloud microphysics. A significant portion of convective precipitation is now handed over to the cloud scheme, where it is subject to advection and evaporation. This addresses the long-standing issue in the IFS of stationary convective precipitation, improving the representation of how precipitation propagates inland from the coast. Verification against radar observations shows that forecasts for precipitation over Europe and the USA have improved (see Figure 1).

The Stochastically Perturbed Parametrizations (SPP) scheme has been revised to address indications of excessive near-surface windspeeds in the ensemble (ENS). The SPP perturbations to surface momentum fluxes have been reduced by using a narrower range of random numbers and applying them with a uniform rather than log-normal transformation. These changes reduce the ensemble spread (the variance across ensemble

members) in 10-metre wind speeds, especially over oceans, while maintaining ensemble reliability.

To improve the realism of initial conditions in the ENS, particularly for tropical cyclones, a new method called scale-selective re-centring has been introduced in the EDA. Re-centring is now only applied to large-scale upper-air fields, centring them on the control forecast, while small-scale structures come directly from the EDA. This helps avoid unrealistic 'double-centred' tropical cyclones from appearing at the start of the ENS forecasts (see Figure 2).

The operational ocean system has been upgraded to NEMO4-SI³, replacing the NEMO 3.4 + LIM2 configuration, introducing a multicategory sea ice model with prognostic salinity and meltpond dynamics, and an improved representation of the upper surface layers of the ocean. Partial coupling is switched off to enable fully coupled ocean-atmosphere forecasts, meaning the atmosphere now uses sea surface temperatures (SSTs) directly from the ocean model, replacing the previous approach – used outside the tropics – where analysed

SSTs were combined with ocean model tendencies. The upgrade includes the coupling of snow depth and sea ice thickness from the sea ice model to the atmosphere, to allow snow over sea ice and variable ice thickness to be represented in the atmospheric forecast model. The improvements in sea ice concentration, upper-ocean mixing, SST diurnal cycle and thermodynamic consistency significantly reduce long-standing biases and enhance the realism and variability of ocean forecasts, while also halving the computational cost via single-precision arithmetic (Keeley et al., 2024).

The ocean wave model includes important scientific changes to its interaction with sea ice. Waves are now attenuated within the ice using the SI³ model when sea ice concentrations are above 30%, rather than being completely blocked, improving realism near the ice edges (Kousal et al., 2025).

On land, a new glacier scheme replaces the previous binary glacier mask with one that accounts for how much of the grid area is covered by ice and uses a four-layer land-ice scheme. This enables more accurate representation of snow and surface energy processes over fully and partially glaciated grid points, particularly in high-latitude and mountainous regions such as Greenland (Arduini et al., 2025).

In the stratosphere, vertical diffusion has been reduced under stable conditions, and the parametrized non-orographic gravity wave drag – representing the effect of atmospheric waves (not linked to mountains) that transport momentum and influence stratospheric winds – has been revised. This improves the representation of the QBO in the analysis and in forecasts on all time scales. In 50r1, QBO has a stronger amplitude and more realistic vertical descent (see Figure 3). Reduced vertical diffusion

also helps to limit excessive moisture leakage from the troposphere into the stratosphere in the analysis and forecasts.

Other updates include:

- Revised aerosol climatology for radiation, which helps to improve tropical tropospheric temperatures.
- Reordering of physics, with vertical diffusion now applied last, improving near-surface 10-metre winds over the ocean.
- Revised wave model bathymetry, improving surface wave realism.
- Use of surface currents in the wave model to account for refraction, resulting in reduced smoothing of wave fields.
- For calculating trajectories and in the minimisation, a small amount of off-centring was introduced in the semi-Lagrangian time-stepping method. This change noticeably improves how well the model fits stratospheric observations and leads to a modest improvement in stratospheric forecast skill.

Data assimilation and observation usage

IFS Cycle 50r1 introduces a significant step towards a more coupled data assimilation system, with an implementation of an outer-loop coupling type framework similar to that used in CERA reanalyses (Laloyaux et al., 2018) and building on the RADSST prototype (McNally et al., 2022).

First, the trajectories used to compare the model with observations are coupled between the atmosphere and ocean, allowing for more consistent representation of air-sea interactions during the assimilation window – the

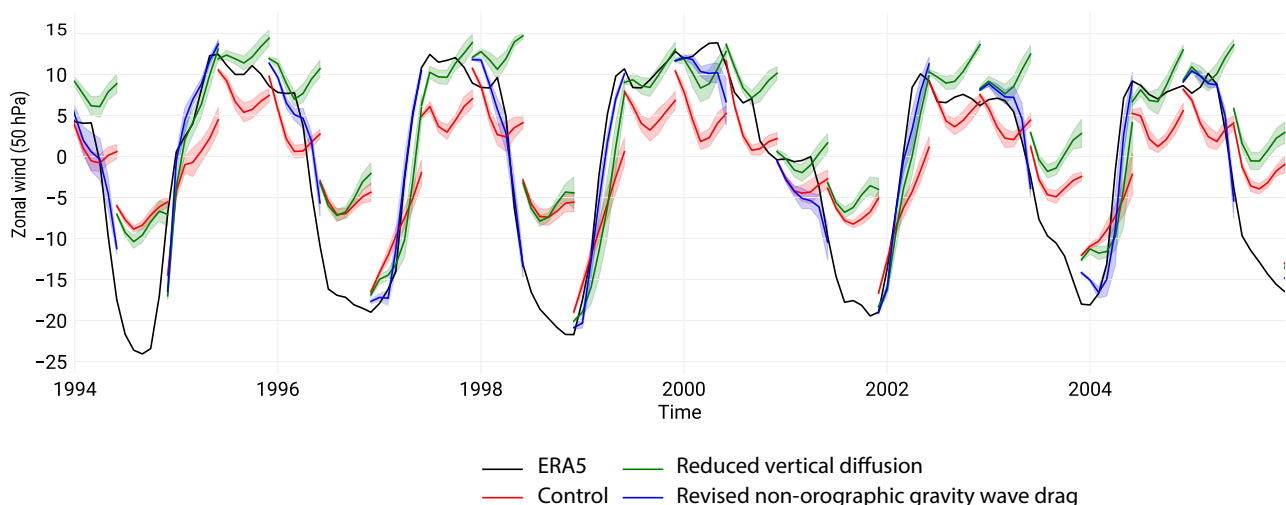


FIGURE 3 Time series of zonal-mean zonal wind at 50 hPa, averaged over the equatorial belt (5°N–5°S), showing the quasi-biennial oscillation in ERA5 reanalysis and in subseasonal-to-seasonal ensemble forecasts. The red line shows forecasts without reduced vertical diffusion; the green line includes reduced vertical diffusion in stable conditions; and the blue line includes both reduced vertical diffusion and the revised non-orographic gravity wave drag formulation to be introduced in Cycle 50r1. The revised configuration (blue) shows much better agreement with the reanalysis (ERA5). Credit: Annelize van Niekerk.

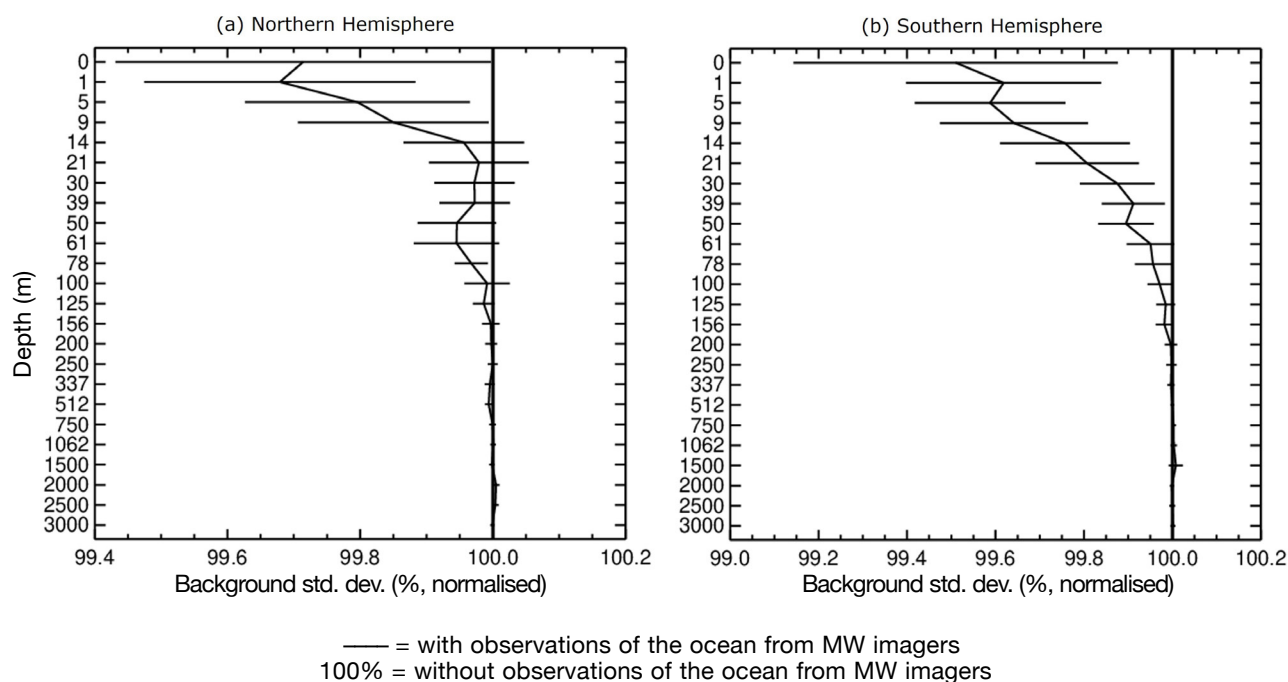


FIGURE 4 Relative change in the standard deviation of the background departures from ARGO floats when observations of ocean temperature from the microwave imagers are included in the coupled system. For (a) the Northern Hemisphere above 20°N and (b) the Southern Hemisphere (below 20°S) for the period 7 June 2022 to 31 August 2022 and 7 December 2022 to 28 February 2023 for the 00 UTC cycles. Credit: Tracy Scanlon.

period over which observations are used to update the model's state.

Second, three-dimensional (3D) ocean and sea ice increments are computed in parallel to the 3D atmospheric increments. Although the ocean and atmosphere are adjusted separately, the system now makes a better use of select instruments with strong surface sensitivities. In this way, Level 1 data from low Earth orbit microwave instruments and geostationary infrared instruments are for the first time providing a constraint to the ocean and sea ice. This improves consistency between the coupled

components and improves the accuracy of each (see Figure 4).

Ocean and sea ice initial conditions for these coupled analyses still come from an ocean long-window analysis generated in a weakly coupled manner and referred to as outer-loop coupled data assimilation (OLDA). For the first time, this ocean analysis is based on the same IFS cycle as other streams and will be available in ECMWF's Meteorological Archival and Retrieval System (MARS) (under stream OLDA). Its initial conditions are taken from the ORAS6 reanalysis, ensuring long-term consistency.

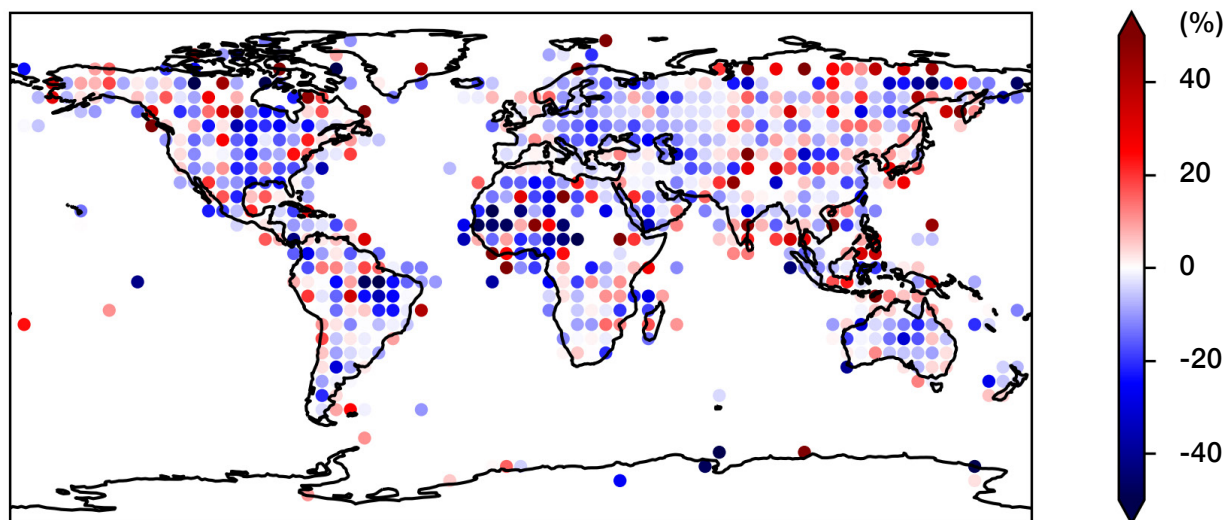


FIGURE 5 Change in root mean square (RMS) first-guess departure (in %) for 2-metre temperature for IFS Cycle 50r1 when compared to observations assimilated in IFS Cycle 49r1. Statistics have been computed over July and August 2024, blue (red) means a reduction (increase) in RMS for IFS Cycle 50r1. Credit: Patrick Laloyaux.

			ccaf/seeps	rmsef/sdef	ccaf/seeps	rmsef/sdef	ccaf/seeps	rmsef/sdef
an	z	50						
		100						
		250						
		500						
		850						
	msl							
	t	50						
		100						
		250						
		500						
		850						
	2t							
	vw	50						
		100						
		250						
		500						
		850						
	10ff							
	r	250						
		700						
	10ff@sea							
	swh							
	mwp							
ob	z	50						
		100						
		250						
		500						
		850						
	t	50						
		100						
		250						
		500						
		850						
	2t							
	vw	50						
		100						
		250						
		500						
		850						
	10ff							
	r	250						
		700						
	2d							
	tcc							
	tp							
	swh							

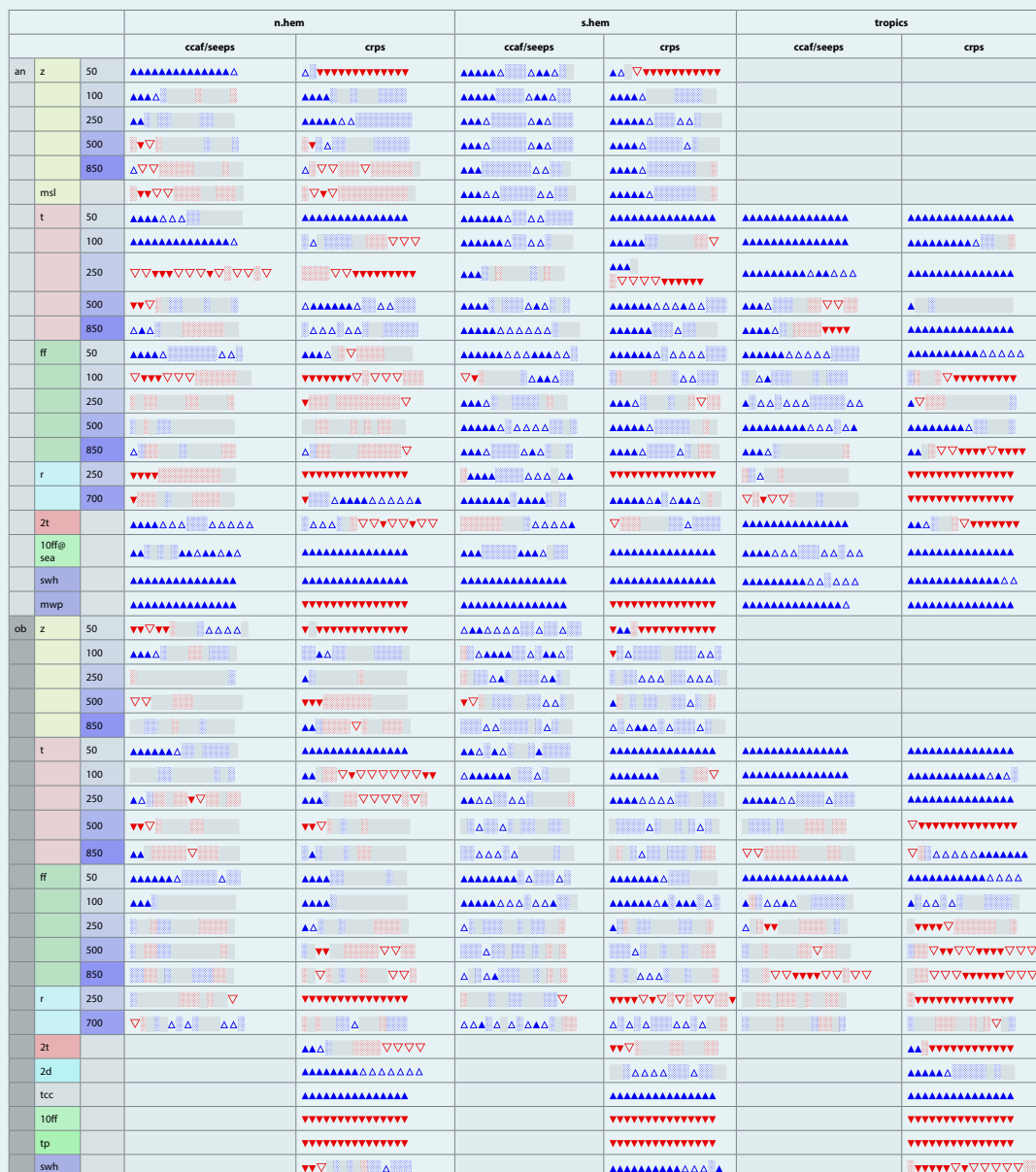
cacf=Anomaly correlation,maef=Mean absolute error,rmsef=Root mean square error,sdaf=Standard deviation of forecast anomaly,sdef=Standard deviation of forecast error,seeps=Stable Equitable Error in Probability Space

Each error plot is converted into a sequence of symbols (e.g. ▼▼■▲▲) where each symbol indicates for given time step whether the experiment is significantly better or worse than the control on different confidence levels.

Symbol legend: for a given forecast step...

- ▲ experiment **better** than control statistically **significant with 99.7% confidence**
- △ experiment **better** than control statistically **significant with 95% confidence**
- ▢ experiment better than control statistically **significant with 50% confidence**
not really any difference between control and experiment
- ◼ experiment worse than control statistically **significant with 50% confidence**
- ▼ experiment **worse** than control statistically **significant with 95% confidence**
- ▽ experiment **worse** than control statistically **significant with 99.7% confidence**

FIGURE 6 Summary scorecard comparing the difference between control forecasts from IFS Cycle 50r1 and IFS Cycle 49r1 using anomaly correlation coefficients and the root mean square error (RMSE). Note that total precipitation is evaluated using the Stable Equitable Error in Probability Space (SEEPS) score rather than correlation, and wave parameters are evaluated using the standard deviation of errors rather than RMSE. Blue symbols and shading indicate improvements in IFS Cycle 50r1 with respect to IFS Cycle 49r1. Red symbols and shading indicate degradation. Scores are calculated from over 420 forecasts initialised at 00 and 12 UTC between 1 May 2024 and 14 July 2025.



ccaf=Anomaly correlation,maef=Mean absolute error,rmsef=Root mean square error,sdaf=Standard deviation of forecast anomaly,sdef=Standard deviation of forecast error,seeps=Stable Equitable Error in Probability Space

Each error plot is converted into a sequence of symbols (e.g. ▼▼▲▲) where each symbol indicates for given time step whether the experiment is significantly better or worse than the control on different confidence levels.

Symbol legend: for a given forecast step...

- ▲ experiment **better** than control statistically **significant with 99.7% confidence**
- ▲ experiment **better** than control statistically **significant with 95% confidence**
- ▲ experiment **better** than control statistically **significant with 50% confidence**
- not really any difference between control and experiment
- ▼ experiment **worse** than control statistically **significant with 50% confidence**
- ▼ experiment **worse** than control statistically **significant with 95% confidence**
- ▼ experiment **worse** than control statistically **significant with 99.7% confidence**

FIGURE 7 Summary scorecard comparing the difference between ensemble forecasts with IFS Cycle 50r1 and IFS Cycle 49r1, using the anomaly correlation coefficient (ACC) of the ensemble mean and the continuous ranked probability score (CRPS). Blue symbols and shading indicate improvements in IFS Cycle 50r1 with respect to IFS Cycle 49r1. Red symbols and shading indicate degradation. Scores are calculated using 50 perturbed ensemble members from more than 117 forecasts initialised at 00 UTC between 1 June 2024 and 21 June 2025.

One of the key purposes of this cycle is to improve the computational efficiency of the IFS. A significant step is the implementation of single-precision computation in the coupled atmosphere–ocean trajectory – where the ocean and atmospheric models are run together and so remain consistent. Efficiency gains were also made in the EDA by running the first minimisation at a reduced horizontal

resolution, from TL399 to TL255. Together, these adjustments reduce computational requirements by about 40%, while maintaining the quality of the ensemble background error estimates.

Another significant improvement of this cycle is the modification to the weak-constraint 4D-Var system, so that biases in the model are now evolving over the full

12-hour data assimilation window. To account for the diurnal variations in model error, the correction in 50r1 follows a first-order Fourier decomposition over time. This is implemented for the stratosphere, the boundary layer and the top soil temperature level. The result is significant improvements in the boundary layer, including a 3% reduction in the root mean square first-guess departure – the difference between the first trajectory of the new assimilation cycle and the observations – for 2-metre temperature (T2m) when compared to IFS Cycle 49r1 (see Figure 5). By reducing model biases in the boundary layer and therefore better constraining the model's atmospheric mean state, the system can now assimilate T2m observations over the full 12-hour window instead of just the first six hours.

The treatment of humidity in the upper troposphere and lower stratosphere (UTLS) has also been improved within the 4D-Var analysis. Previously, humidity increments in the stratosphere were artificially set to zero, limiting the ability of the system to adjust humidity fields here. Removal of this constraint has allowed the analysis to produce physically consistent humidity increments throughout the UTLS. In addition, the vertical coverage of radiosonde humidity observations has been extended up to 60 hPa. This provides improved observational constraints in the lower stratosphere, contributing to a more accurate and dynamically consistent representation of moisture in the UTLS (Semane and Bonavita, 2025).

Other updates include:

- Upgrading of the radiative transfer model to RTTOV-14.0, which improves the accuracy of radiance simulations.
- Upgrading the surface emissivity model over sea ice, so it can now be used up to 183 GHz compared to the previous upper limit of 89 GHz. This applies to all-sky microwave channels and would improve the analysis in polar regions under cloudy conditions.
- The spatial density of geostationary satellite data has been increased by reducing the minimum spacing used to select the data – the thinning distance – from 125 km to 75 km, and the time resolution has been improved by using hourly data. In parallel, window channels – frequency bands where the atmosphere is relatively transparent – have been included in the assimilation.
- Observations are now re-selected – a process known as re-screening – for every trajectory of the outer-loop framework to ensure consistent use of the best data, based on a better knowledge of the atmospheric state.
- The length of the observation timeslots has been reduced from 30 minutes to 15 minutes, allowing for a more accurate comparison between the model and the observations. The observations are clustered into

'timeslots' over the 12-hour assimilation window, with all the observations within a given timeslot assigned the same time (rather than their 'true' time).

- A different method has been introduced to compute the background error standard deviation from the EDA, giving a more realistic spread distribution between the extra-tropics and the tropics.
- Wind increments derived from ozone-sensitive observations in the lower and mid-stratosphere have been restored, avoiding regions where heterogeneous chemistry may occur.

Impact on medium-range and sub-seasonal forecasts

Scorecards summarising forecast performance for the control forecast and the ENS are shown in Figure 6 and Figure 7, respectively. Both scorecards are predominantly blue, indicating that the new IFS Cycle 50r1 generally improves the forecast skill across a wide range of variables and lead times.

Improvements in both the control forecast and ENS include:

- Forecasts of QBO improved by up to 15%, due to reduced vertical diffusion and the revised non-orographic gravity wave drag formulation.
- Temperatures and winds at 850 and 250 hPa in the tropics improved by up to 7%, with contributions from the updated aerosol climatology, revised convection scheme and reordering of physics.
- Forecasts of total cloud cover, dewpoint temperature and 10-metre winds over sea improved by 1–2%, largely due to changes in the physics of the model.

Degradations in both the control forecast and ENS include:

- 250 hPa relative humidity – evaluated using root mean square error (RMSE) and continuous ranked probability (CRPS) scores – degraded by around 2%.
- 50 hPa geopotential height (using RMSE and CRPS) degraded by up to 15%, mainly due to a shift in mean values associated with the revised aerosol climatology.
- Forecasts of 2-metre temperature in the tropics degraded by 1–2% (using RMSE and CRPS), due to a bias shift linked to changes in the physics of the model (including aerosol climatology update), resulting in slightly colder-than-observed temperatures over land.

Forecast accuracy for total precipitation and 10-metre winds has improved by 1–2% in both the control forecast and the ensemble mean, using RMSE (see also Figure 1 for radar-based rainfall verification). The Stable Equitable Error in Probability Space (SEEPS) score also shows

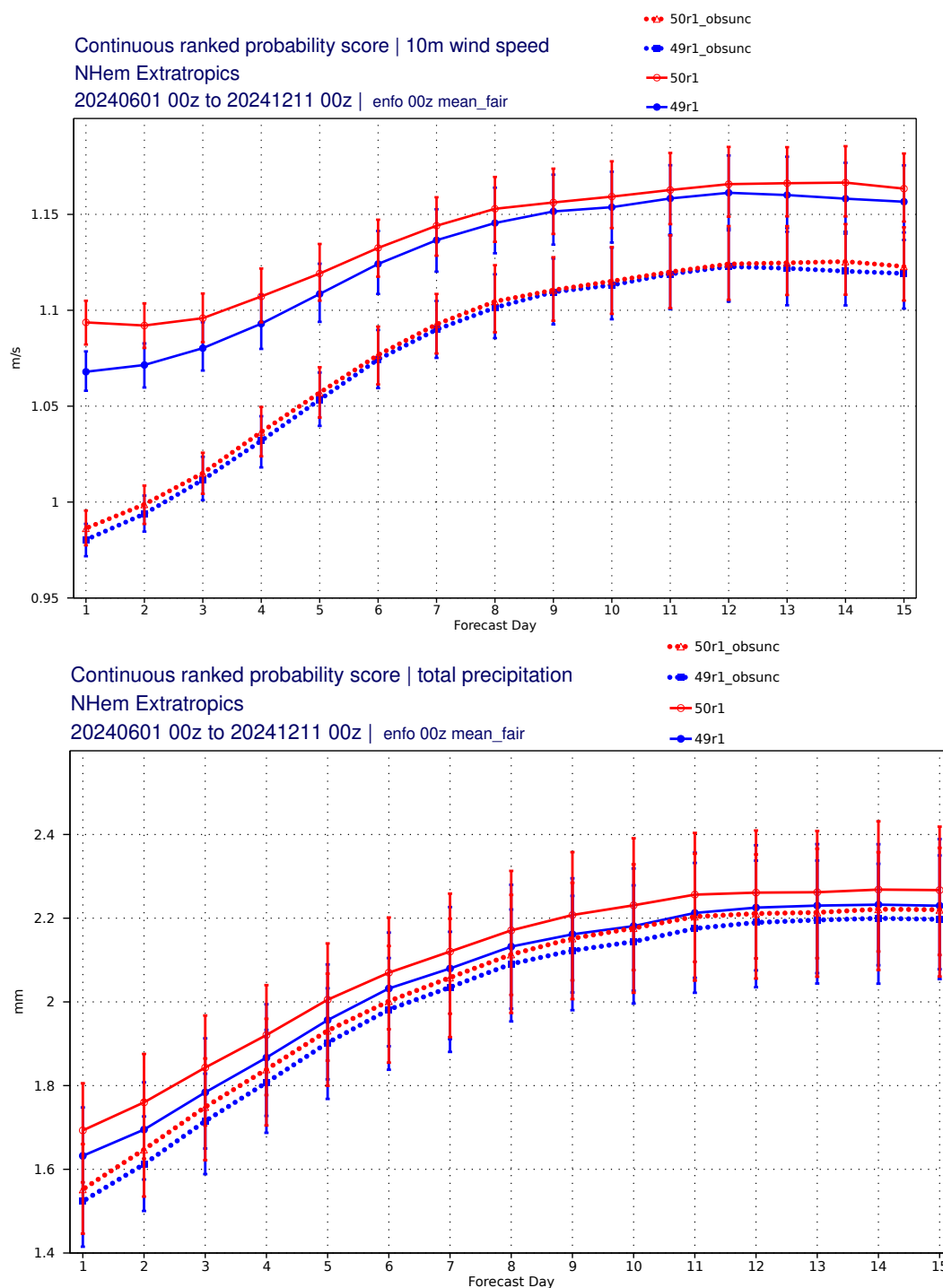


FIGURE 8 Continuous ranked probability score (CRPS) for (top) 10-metre winds and (bottom) total precipitation from Cycle 49r1 (blue) and Cycle 50r1 (red), verified against observations and averaged over the Northern Hemisphere extra-tropics. The solid lines show CRPS without accounting for observation uncertainty and the dotted lines show CRPS when accounting for observation uncertainty. All scores are calculated using 50 perturbed members from 77 forecasts initialised daily between 1 June 2024 to 5 August 2024 and between 1 December 2024 and 11 December 2024.

improvement for total precipitation in the control forecast. However, when evaluated using CRPS, these variables show degradations of up to 3% in the ENS. These degradations in 10-metre winds can largely be explained by the revision of the SPP scheme, which significantly reduces ensemble spread (by 15% for 10-metre winds), addressing the spurious wind extremes and spread present in Cycle 49r1. However, when accounting for

observation uncertainty in the form of representativeness errors (Bouall  gue, 2020), verification shows that 10-metre wind CRPS scores are nearly comparable between Cycles 49r1 and 50r1, and the apparent degradation in total precipitation CRPS is halved (Figure 8).

The remaining degradation in total precipitation CRPS score in the ENS is attributed to physics changes in the

model that result in a slight shift in the precipitation distribution. Cycle 50r1 produces approximately 1% more precipitation overall, with a small shift toward lighter rainfall amounts at the lower end.

Small improvements to tropical cyclone intensity and position forecasts have been observed in the control forecast. At the sub-seasonal time range (up to 46 days ahead), the most notable improvements come from the enhanced representation of the QBO, sea-surface temperatures and sea ice, with benefits that persist across all lead times.

System configuration changes and updated products

IFS Cycle 50r1 does not introduce changes to the horizontal or vertical resolution. However, there will be several product updates. The high-resolution deterministic forecast (HRES) will be retired as a separate product and instead moved under the control forecast category in the MARS archive and in dissemination. In addition, ocean long window analysis data will also be made available in MARS.

Summary and outlook

IFS Cycle 50r1 brings major advances in both the forecast model and the data assimilation system, marking a

significant step forward in coupled Earth system prediction. The model upgrade includes the introduction of the NEMO4-SI³ ocean and sea ice model, improved wave–ice interactions, revised vertical diffusion and gravity wave drag in the stratosphere, changes to the convection scheme, a new glacier scheme, and a revised SPP scheme that reduces excessive near-surface wind spread in the ensemble.

On the data assimilation side, a new atmosphere–ocean coupled analysis configuration enables assimilation of Level 1 satellite data into the ocean and sea ice, while weak-constraint 4D-Var introduces time-varying model errors and has been extended to the boundary layer.

Cost-efficiency improvements have been made through the use of single-precision trajectories, single-precision ocean model and from reducing the resolution of the first minimisation in the EDA. The system now allows humidity increments in the stratosphere, addressing longstanding issues in moisture analysis at these levels.

Together, these upgrades improve the representation of stratospheric dynamics, tropical upper-air structure, and the interactions between ocean, sea ice and the atmosphere, while reducing computational cost and laying the foundation for future advances in coupled data assimilation.

Further reading

Keeley, S., K. Mogensen, J.-R. Bidlot, M. Balmaseda and S. Hatfield, 2024: Introduction of a new ocean and sea ice model based on NEMO4-SI3. *ECMWF Newsletter* **No. 180**, 24–29. <https://doi.org/10.21957/sk4928ds0a>

Arduini, G., C. Rüdiger and G. Balsamo, 2025: An improved glacier parameterisation for the ecLand land-surface model: local, regional and global impact, *EGUsphere* [preprint], <https://doi.org/10.5194/egusphere-2025-2454>

Kousal, J., J. Bidlot, J. Rabault and M. Müller, 2025: The introduction of waves in sea ice. *ECMWF Newsletter* **No. 185**, 18–19 <https://www.ecmwf.int/en/elibrary/81689-newsletter-no-185-autumn-2025>

Laloyaux, P., E. de Boisseson, M. Balmaseda, J.-R. Bidlot, S. Broennimann, R. Buizza, et al., 2018: CERA-20C: A coupled reanalysis of the twentieth century. *J. Adv. Model. Earth Syst.*, 10, 1172–1195. <https://doi.org/10.1029/2018MS001273>

Semane, N. and M. Bonavita, 2025: Reintroducing the analysis of humidity in the stratosphere. *ECMWF Newsletter* **No. 183**, 28–31. <https://doi.org/10.21957/ns41h80kl3>

Ben-Bouallègue, Z. 2020: Accounting for representativeness in the verification of ensemble forecasts. *ECMWF Tech. Memo.* 865. <https://doi.org/10.21957/5z6esc7wr>

McNally, T., P. Browne, M. Chrust, D. Fairbairn, S. Massart, K. Mogensen and H. Zuo, 2022: Progress on developing a new coupled sea-surface temperature analysis. *ECMWF Newsletter* **No. 172**, 17–22. <https://doi.org/10.21957/tm4913hs8d>

Acknowledgements

We thank Llorenç Lledó, Annelize van Niekerk, Sarah-Jane Lock, Martin Leutbecher, Tracy Scanlon, Patrick Laloyaux, Philip Browne, Sarah Keeley, and Gabriele Arduini for providing figures and valuable input to this article.

Looking back on 10 years of climate monitoring by the Copernicus Climate Change Service

10 years that are the ten warmest calendar years on record for the globe

Freja Vamborg, Anna Lombardi, Adrian Simmons, David Lavers, Francesca Guglielmo, Julien Nicolas, Rebecca Emerton, Samantha Burgess

In September 2015 the Copernicus Climate Change Service (C3S) published its first temperature summary (<https://climate.copernicus.eu/average-surface-air-temperatures-august-2015>), covering global and European statistics for the previous month and year. Stemming from a discussion between reanalysis scientists and those with communications roles at ECMWF, it was the first public climate monitoring communication from C3S. It built on the vision that climate monitoring in near-real time with a global and pan-European perspective would be one of the key pillars of C3S, complementing activities at the national level and to be implemented by ECMWF in cooperation with contracted partners across Europe.

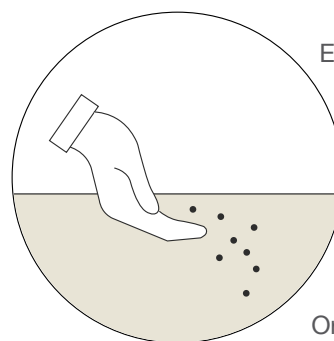
While workflows and communication products have evolved, many of the underpinning thoughts and approaches remain the same. The changes have been driven by an increased cross-community awareness of climate monitoring possibilities and data availability, but also by user and stakeholder demand.

The scientific and technical team behind the monitoring has also evolved over time, from a few individuals across several parts of C3S, growing into a dedicated 'Climate Intelligence' team within ECMWF and leveraging expertise across the Copernicus community. In this article, this team reflects on ten aspects that have shaped C3S monitoring activities and provides a glimpse into how we are imagining the future.

Preparing the ground

"By 2015 we were sure our data were suitable for monitoring key aspects of Earth's changing climate and had been charged with implementing C3S' mission to provide consistent and authoritative information on climate change. C3S colleagues have done an outstanding job of evolving our initial monthly temperature updates into a comprehensive and accessible set of monthly, seasonal and annual reports." Adrian Simmons, writer of the first bulletin.

Prior to 2015 and the launch of C3S-led activities,



ECMWF was already contributing to various international monitoring efforts, such as the Bulletin of the American Meteorological Society State of the Climate and World Meteorological Organization (WMO)-led reports. Working with others in

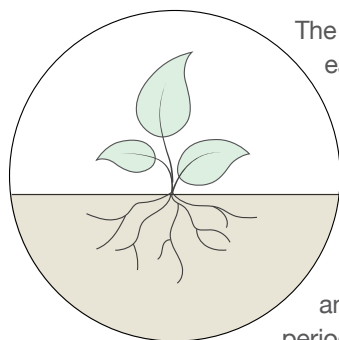
the climate community, ECMWF had invested heavily in producing reanalyses that had been proven, as documented in the scientific literature and in the 4th assessment cycle of the Intergovernmental Panel on Climate Change (IPCC AR4), to be fit for monitoring some of the key atmospheric variables.

By 2015, the then state-of-the-art reanalysis ERA-Interim was thus deemed to be reliable for monitoring several variables, including global surface air temperature. Major efforts had also been invested by the in situ and space-based observational communities to produce quality-assured products, paving the way for multiple lines of evidence to be used in climate monitoring. These developments laid the foundations for climate monitoring to become a key pillar of C3S.

The temperature summary, published monthly from September 2015 onward, has grown over time to include more details on Europe and the polar regions. Separate summaries for hydrological variables and sea ice were introduced in 2017, and the name Climate Bulletin (<https://climate.copernicus.eu/climate-bulletins>) was adopted soon after. Timely delivery has been a driving factor, and this product continues to mostly rely on reanalysis, which remains one of the first climate-quality datasets to be updated each month for the relevant variables. The most recent additions to the Climate Bulletins include the monitoring of sea-surface temperature, daily variations in some variables, and occasional inclusions of additional topics of interest. Other more technical but time-consuming developments include the transition from ERA-Interim to ERA5 in 2019 and to the 1991–2020 reference period in January 2021.

From pilot to flagship product

“Having grown over time from a collection of analyses and articles to a dedicated report, the Global Climate Highlights, published each January, provide timely and concise information on the climate of the previous year. The relevance of providing fit-for-purpose global climate monitoring products is internationally acknowledged as an essential instrument to inform policy making strategies.” Francesca Guglielmo, Global Climate Highlights lead editor.



The final Climate Bulletin of each year, published in early January, became a key opportunity to look back on global temperatures of the previous calendar year and how they compare to the recent past and to the pre-industrial period (Figure 1). The near-real-

time nature of ECMWF’s reanalyses, supported by other global temperature datasets, allows C3S to be the first to be able to report on the previous year’s global temperature.

Temperature monitoring remains crucial, especially in the context of the Paris Agreement. Even before its adoption at the United Nations Framework Convention on Climate Change (UNFCCC) Conference of the Parties (COP) in 2015, global temperature was already considered a key indicator for human-induced climate change. The Paris Agreement reinforced this by setting specific thresholds: preferably below 1.5°C and well below 2°C above pre-industrial levels.

Alongside annual temperature averages, our approach has also been to provide five-year averages in line with the regular UNFCCC Global Stocktakes. Our team continues to refine the way ERA temperatures relate to the pre-industrial period, aligning as closely as possible with the latest IPCC reports, WMO and climate community activities.

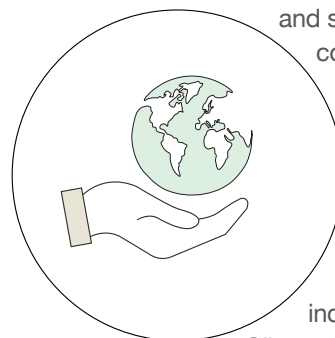
This end-of-year release has gradually grown in scope, starting with the inclusion of trends in greenhouse gas concentrations for the 2018 edition, in collaboration with the Copernicus Atmosphere Monitoring Service. Since the 2023 edition, it completed its transformation to what is now called the ‘Global Climate Highlights’ (<https://climate.copernicus.eu/global-climate-highlights>) (GCH). This report includes analysis of global surface air and sea-surface temperature, greenhouse gas concentration trends and other variables relevant to significant events or topics of the previous year.

The GCH 2024 marked an exception in that Berkeley Earth, ECMWF, NASA, NOAA, the UK Met Office and the WMO made a concerted effort to coordinate the release of their data, highlighting the exceptional conditions experienced during 2024.

Expanding to an Earth system perspective

“Drawing on the expertise of around 100 scientists across Europe and the rest of the world, the annual European State of the Climate report combines key insights from around 40 different datasets covering a huge range of topics and variables. The ESOTC presents complex climate data in an accessible and engaging way for a broad audience.” Rebecca Emerton, European State of the Climate lead editor.

While global temperature has become the flagship indicator of the Paris Agreement, the Earth system is complex. This is reflected in the Global Climate Observing System (GCOS) concept of Essential Climate Variables (ECVs). ECVs have underpinned the C3S provision of data from reanalysis, in situ and especially the satellite observing system since the start. In 2017, GCOS also defined a set of seven key climate indicators, based on a subset of ECVs, with the necessary quality



and sufficient spatiotemporal coverage to describe the imprint of climate change globally and holistically.

After consultation with stakeholders, such as the European Environment Agency, these GCOS indicators, as well as the Climate Bulletins of 2017, were

taken as a starting point for our team, other colleagues at ECMWF and C3S’ in situ and satellite ECV data providers to design and produce what became the first European State of the Climate (ESOTC) report (<https://climate.copernicus.eu/ESOTC>). This first edition, published in 2018, established the format of a web-based report complemented by a PDF summary, and provided a blueprint for the production workflow, including internal and external scientific review. It covered five global and four European indicators, and included five sections describing the European climate of 2017 in a historical context, mostly focusing on the variables already covered in the Climate Bulletins. The ESOTC is published a few months after the end of the reporting year, in April, and this means more datasets, including not only reanalyses, but also in situ and satellite data and model reconstructions covering most or all of the previous calendar year, are available. This allows information on a much wider range of variables from across the Earth

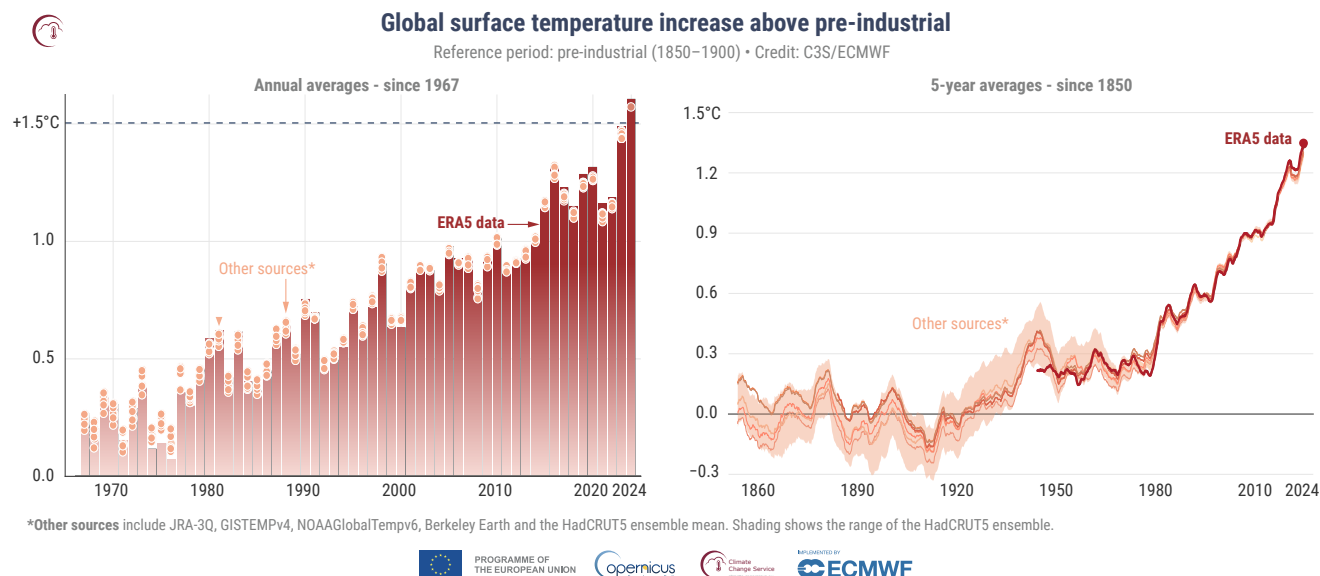


FIGURE 1 Global surface air temperature increases relative to the average for the 1850–1900 pre-industrial reference period, based on several global temperature datasets shown as annual averages since 1967 (left) and as 5-year averages since 1850 (right). Credit: C3S/ECMWF. First published in the C3S Global Climate Highlights 2024.

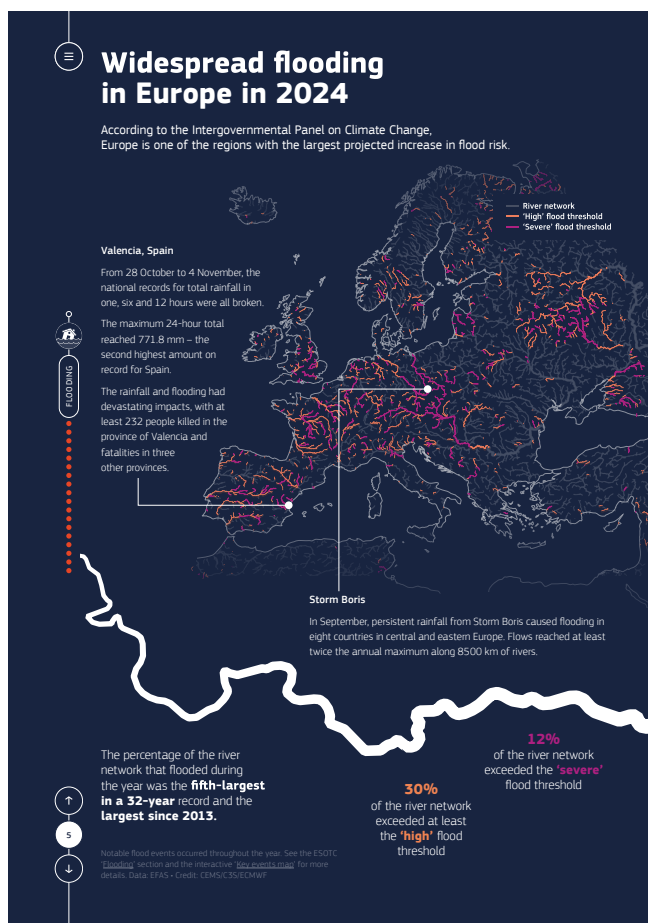
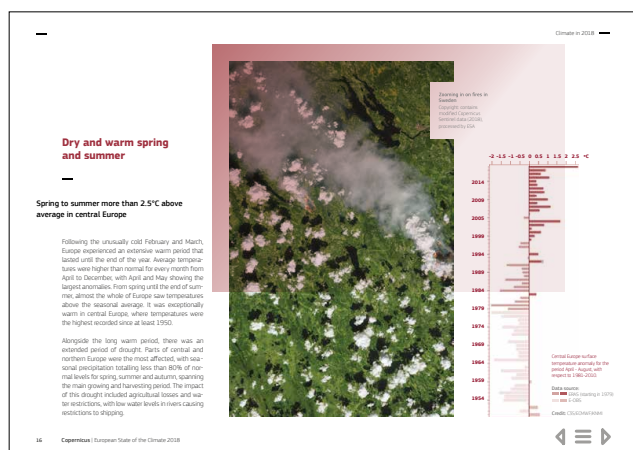


FIGURE 2 Illustration of how the representation of some of the key messages of Spotlight sections has evolved over time in the ESOTC. Examples from the 2018, 2021 and 2024 reports.

system compared to the monthly Climate Bulletins and annual GCH, which are published in near real-time. Since the second edition, known as ESOTC 2018 (describing the 2018 calendar year), the ESOTC now contains around 12 monitoring sections for Europe, ranging from more typical meteorological variables, such as temperature and precipitation, to variables that more closely represent impacts on human and natural systems, such as measures of wildfire danger and emissions, river flow, heat stress and even wind and solar power potential. The ESOTC also includes two or three ‘Spotlight’ sections, which focus on topics unique to the year, such as extreme events, significant regional contrasts or other notable topics. Examples include ‘dry and warm spring and summer’ (<https://climate.copernicus.eu/dry-and-warm-spring-and-summer>) in the ESOTC 2018, ‘the warm winter of northeastern Europe’ (<https://climate.copernicus.eu/esotc/2020/warm-winter>) in the ESOTC 2020 and ‘flooding’ (<https://climate.copernicus.eu/esotc/2024/flooding>) in the ESOTC 2024, particularly associated with storm Boris in central and eastern Europe and flooding in Valencia.

Over the eight editions of the ESOTC, major changes in terms of content have been introduced. For instance:

- The ESOTC 2020 saw the inclusion of a global section, dedicated sections focusing on the Arctic and the separation of the C3S Climate Indicators into their own product.
- The Climate Indicators have increased in number, in most cases covering the globe, Europe and the Arctic, and are described in more detail. The current Indicators are: surface air and sea-surface temperatures, glaciers, ice sheets, ocean heat content, sea ice, sea level, and greenhouse gas concentrations and fluxes.
- Since the ESOTC 2023, which was the first jointly produced with the WMO (described in the collaboration section), the report has included a ‘Climate policy and action’ subsection, covering new topics each year, such as extreme weather and human health, or climate adaptation and resilience to weather and climate extremes.
- The ESOTC 2024 saw one of the biggest overhauls yet, significantly reducing the volume of content and introducing a more streamlined and concise main report. This included removing the global section, as much of this content is now covered by the GCH and in the Climate Indicators. For the first time, the full report was published not only as a microsite, but also as a unified PDF, with a much shorter summary, and the introduction of new resources, such as a graphics gallery.

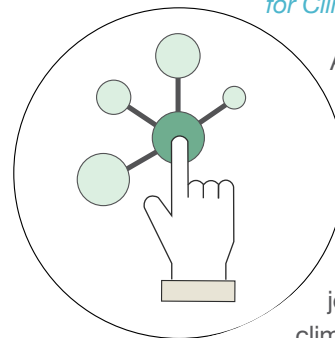
Providing accessible and attractive reports and products

A key consideration across all products, but especially with the ESOTC as a testing ground, is the wish to provide information, text and visuals that are understandable by a variety of non-specialist users and readers. For example, the full ESOTC report goes through several iterations of editorial review by our copy editor to ensure the language is accessible and to remove or explain jargon. To provide a succinct overview of the key messages, a report summary is also created (Figure 2). To highlight key findings, several products have been developed in collaboration with the ECMWF communication team and external collaborators, such as infographics, animations, videos, social media materials, press briefings and much more.



Beyond reporting – interactive exploration of data and insights

“Climate Pulse has led to a new cohort of C3S users having access to climate monitoring data on demand via a simple visual interface and application accessible through different platforms.” Julien Nicolas, scientific lead for Climate Pulse.



An overarching objective of our Climate Intelligence team has been to increase the accessibility of C3S climate data by developing products which offer a tailored user journey across our various climate datasets to a broad audience. The aim is to enable users to explore the data behind our products at their own pace and according to their personal interests, with no need to download and analyse the files. Interactivity is one way of doing this, allowing us to display multiple layers of information at once while ensuring users are not overwhelmed by content.

For example, 2024 saw the introduction of interactive and responsive charts within the ESOTC. Enabling users to explore data directly within the charts and to add extra layers of information, these features have since also become an integral part of the Climate Bulletins and the GCH.

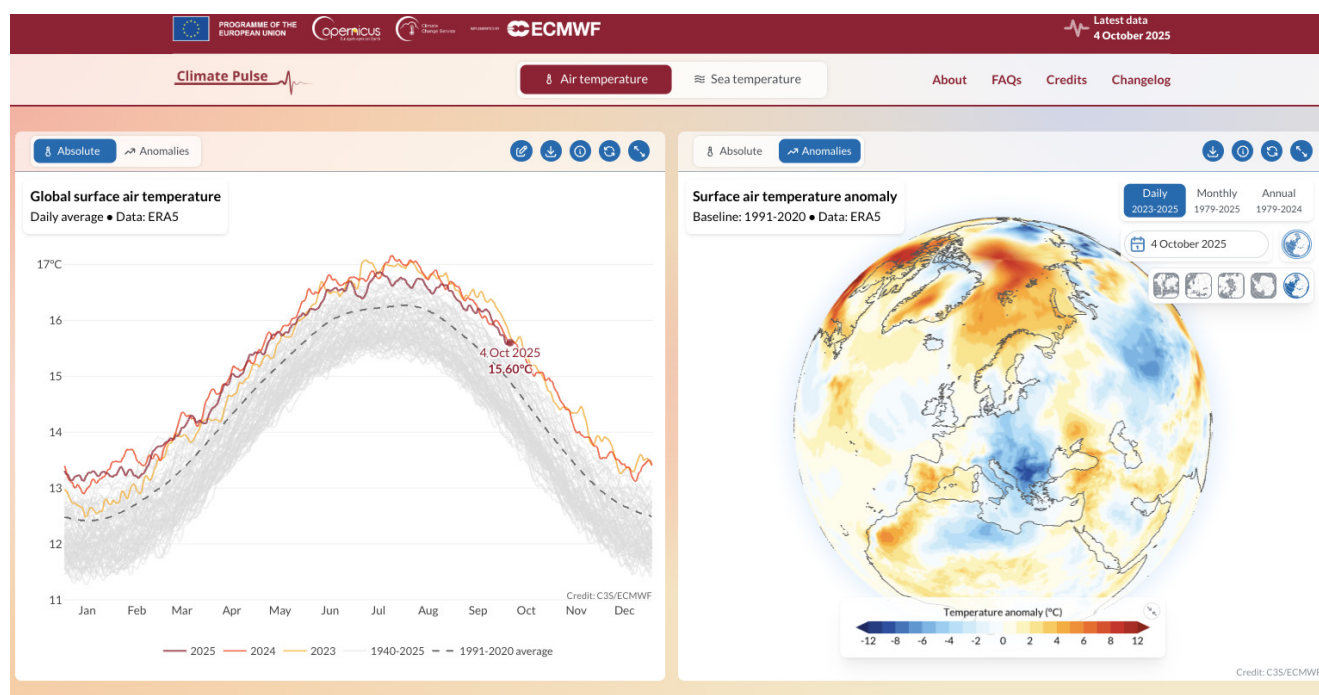


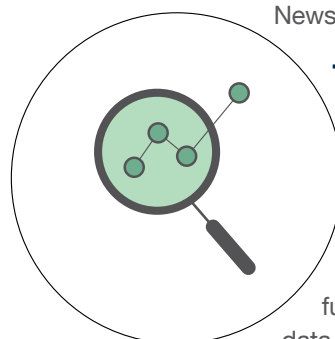
FIGURE 3 Preview of an upgraded version of Climate Pulse, with easier navigation between daily, monthly and annual values, and the possibility to choose alternative map views.

Another interactive development introduced in 2024 was the web application Climate Pulse (<https://pulse.climate.copernicus.eu/>) (Figure 3). This application extends beyond the monthly means and anomalies typically considered in the Climate Bulletins, providing daily time series and maps of surface air and sea surface temperature actual values and anomalies. It was our response to the surge in demand – both internally and from the public – to track developing global air and sea-surface temperatures, especially as daily records were being broken by a large margin in 2023 (<https://climate.copernicus.eu/copernicus-and-wmo-july-2023-track-be-hottest-month-record>). The app is based on ERA5 data, available just two days behind real time, and allows users not only to monitor current conditions without waiting for our monthly reports, but also to place them in the context of previous months and years. An updated version of Climate Pulse that will improve exploration at a regional level was released in October 2025.

Only 18 months after launch, the take-up of this application is already impressive, with 600 to 1,000 unique users per day, and it is used internally to stay abreast of the most recent fluctuations in global temperatures.

Interactive monitoring applications are now becoming an important cornerstone of our products. The latest is Thermal Trace, published in August 2025, which allows

users to explore heat and cold stress across the globe and their changes over time (see separate article in this Newsletter).



Traceable access to underlying data and information

Climate monitoring relies on high-quality data and can only be described as fully transparent once the data and the processing

methods it builds on are made freely available. The provision of accessible data and associated documentation is also the primary mission of the Copernicus programme.

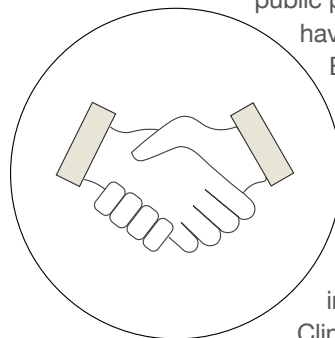
A key step towards free and open data was the publication of the gridded ERA5 dataset, along with post-processed data, including monthly and 12-monthly climatologies and anomalies, in the Climate Data Store, just a few months after the service's beta-launch in 2018. For a long time, the data underlying the graphics in the Climate Bulletins were only made available for timeseries and only for key charts in other reports. A step-change came with the ESOTC 2023, which allowed users to not only download the high-resolution charts, but also to access the post-processed data behind them. In the following year, the GCH and ESOTC 2024 were

accompanied by bespoke graphics galleries collecting all charts discussed in the reports together with supplementary figures. This allows users to quickly retrieve all graphics from a report from a single location. The team is currently developing a similar gallery for the Climate Bulletins. But while much progress has been made, there is work to do, such as providing access to the code that converts raw data to post-processed output, and providing traceable information even further up the data processing chain, such as that ingested into ERA5.

Collaboration as a key to success

While high-quality data, well-designed software and scientific workflows now underpin C3S' climate monitoring, none of what has been achieved so far could have been done without collaboration.

The monitoring activities started within the ECMWF reanalysis team, but it was an interaction between scientists and communication experts that led to the first public product. Collaborations



have since grown. Within ECMWF, colleagues provide invaluable input to the Climate Bulletins and represent the editorial backbone of the ESOTC and GCH. However, the conception and implementation of both the Climate Indicators and the ESOTC have relied on

collaboration across the Copernicus community and beyond. This has involved data providers, subject experts, and monitoring teams at national meteorological



“ The alarming findings of the European State of the Climate Report show us how important it is to have an independent, world-class Earth observation system. As such, Copernicus makes a crucial contribution to resilience and preparedness in the EU. This is both in support of Europe's efforts to mitigate the effects of climate change and to lead the new economy that will emerge.”

**ANDRIUS
KUBILIUS**

EU Commissioner
for Defence and Space



“ At ECMWF, we are grateful for the European Commission's continued support towards the Copernicus programmes for Climate Change and Atmosphere Monitoring Services, as well as their support of our contribution to the Copernicus Emergency Management Service. The 2024 ESOTC report is a testament to the dedication of our staff and collaborators, whose excellent work makes it possible to produce such a high-quality and well-regarded publication.”

**FLORENCE
RABIER**

Director-General,
ECMWF



“ WMO collaborates with the Copernicus Climate Change Service and other partners to strengthen the provision of climate information and services. These are essential to increase resilience to extreme weather and climate impacts. WMO is committed to expanding early warning systems. We are making progress but need to go further and faster.”

**CELESTE
SAULO**

Secretary-General,
WMO

FIGURE 4 The 2024 edition of the European State of the Climate report was endorsed by Andrius Kubilius, EU Commissioner for Defence and Space, and Celeste Saulo, Secretary-General, WMO.

and hydrological services, who have contributed in different ways to the various phases of production – from conception, analysis and writing to content review, media liaison, and post-publication activities such as online discussion panels.

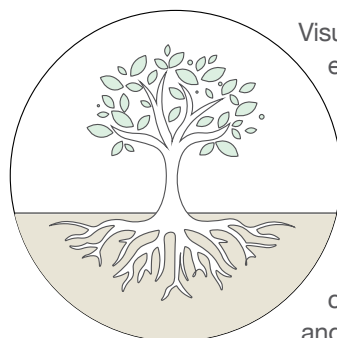
Collaboration with the WMO has been part of ECMWF activities since the start, for instance through our provision of data and editorial input into the WMO Global State of the Climate. In recent years, the WMO started to endorse State of the Climate reports (Figure 4) for its individual Regional Climate Centre (RCC) network regions.

When the WMO European report was first introduced in 2021, ECMWF was coordinating it together with RCC Region VI (Europe), while working in parallel on the ESOTC. Since 2023, the ESOTC has been produced jointly with the WMO, with the aim of providing a single authoritative report for Europe. This collaboration has provided ECMWF with a larger global platform and a new forum in which we can engage with our Member and Co-operating States.

Building a recognisable voice

“The most recent decade of C3S climate monitoring has seen an increase in the exposure of ECMWF in the global media, with climate monitoring data regularly quoted by UN agencies. This recognition results from a strategic vision to ensure that C3S is seen as a trusted voice and a service that can provide data quickly and accurately to enable others to tell the critical stories about the implications of our warming world.” Samantha Burgess, Strategic Lead for Climate.

To build a recognisable voice in climate monitoring takes time, a focus on scientific rigour and continuous reassessment. Here we provide some examples of how we have achieved this and how we quantify the results.



Visual identity is crucial to establishing brand recognition, and to building trust and credibility. We have worked to achieve a consistent look across our climate monitoring communication materials and reports. This includes, for example, the development and

implementation of a clear visual style guide to steer the look and feel of the ESOTC. The same approach is being adopted across all our graphical products.

Another way to ensure broad reach is through effective communication and outreach activities, including engagement with the press and through social media.

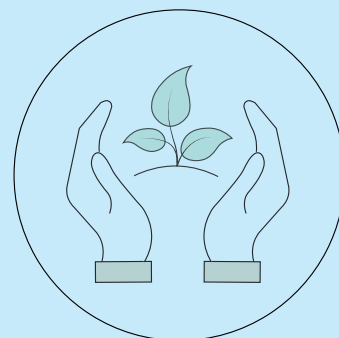
This has been achieved through collaboration between the Climate Intelligence team, the communication team and external partners.

For example, while the temperature summaries from the Climate Bulletins were originally shared with our press

Lessons learnt

Over its ten years of activity, our team has learnt many valuable lessons about the challenges and intricacies of operational climate monitoring and climate

communications. Sticking to our theme of ten, here are ten of the lessons we have learnt along the way:



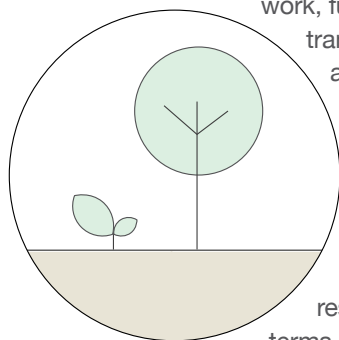
1. Reference periods are unavoidable and will lead to lengthy discussions.
2. Long-term observations are essential for climate monitoring, but their continued availability cannot be taken for granted.
3. Thorough review and scientific detail versus accessible, swift and creative reports is a balancing act.
4. Carefully crafted visuals and text are more effective for communication but require more time and effort to create.
5. Repetition is both your friend and your enemy; reporting on the same quantities and statistics is essential for tracking change but limits the space for exploring new topics.
6. The messages the data reveal are rarely uplifting.
7. Use terms like ‘warmest’, ‘coolest’, ‘wettest’, or ‘driest on record’ with caution, given the varying lengths of data records.
8. ‘Word clouds’ are useful to highlight which words are used most in a report, informing that for us typically these are ‘average’, followed by ‘Europe’ and ‘anomalies’.
9. Climate events follow their own schedule, not ours.
10. Collaboration brings fresh perspectives and expertise in new areas, but requires commitment, flexibility and firm deadlines.

agency and through social media as a few bullet points, every product is now associated with a press release. Since 2021, for the broader products such as the GCH and the ESOTC, the report release has also been accompanied by a press briefing. These changes were made to create further engagement, and to respond and adapt to increased demand.

Success can be measured in several ways, such as the number of mentions of C3S and our products in news media around the world. This has grown from close to 160 for the ESOTC in 2019 to around 15,650 for the latest GCH. The number of different countries covering C3S monitoring has also grown over time. The number of media mentions for the latest GCH release was over three times more than the year before and is a testament to the strength of collaboration with the release of data and of the publication being coordinated across all international groups who operationally monitor global temperatures. Figure 4 illustrates the European and global support for the ESOTC 2024.

Looking ahead

We have looked back ten years, but what is planned for the next ten? In the immediate future, we are working to make the workflow more efficient through increased automation and by exploring how AI could support our work, further improving



transparency and accessibility across the production chain and expanding our visual identity across all products. By early 2027, it is expected that ERA6, the next-generation reanalysis, with higher resolution and advances in terms of the underlying model

and ingested data, will start to become available. We are confident that this will lead to an updated portfolio of monitoring products for our team to rely on. In addition, while the monitoring of extreme events has always been

part of our work, there has been no regular workflow in place that allows close-to-real-time analysis. This will change with the implementation of the new C3S operational attribution office, which will provide tools and workflows to analyse extreme events – starting with temperature extremes – as they happen, while putting them in the context of climate change.

Examining how some end-of-the-year press release titles have evolved in the last decade highlights significant changes in our climate that have already taken place and offers some insight into what the next ten years might bring.

In 2017, the title was ‘Earth on the edge: Record breaking 2016 was close to 1.5°C warming’ (<https://climate.copernicus.eu/earth-edge-record-breaking-2016-was-close-15degc-warming>) and in 2025 ‘Copernicus: 2024 is the first year to exceed 1.5°C above pre-industrial level’ (<https://climate.copernicus.eu/copernicus-2024-first-year-exceed-15degc-above-pre-industrial-level>). In the first case, it referred to the month of February 2016 nearing the 1.5°C threshold and in the second case the whole calendar year had passed the threshold. While the underlying increase is largely related to the human-induced greenhouse gas concentration increases in the atmosphere, both 2016 and 2024 temperatures saw a temporary boost due to the influence of El Niño. It is not hard to imagine that we will soon have such cases without that boosting influence. Based on the estimates provided by the ‘C3S Global Temperature Monitor’ (<https://apps.climate.copernicus.eu/global-temperature-trend-monitor/?tab=source-code>) over the last five years or so, the long-term 1.5°C threshold will be breached sometime between 2028 and 2032.

It is not just the Paris Agreement temperature thresholds that matter, but all the associated changes across the Earth system, which become increasingly apparent with every additional fraction of a degree. So, C3S monitoring will continue, with the hope of being the bearer of more positive news at some point.

Over the past decade, the monthly climate bulletin has grown into one of the cornerstones of the Copernicus Climate Change Service. What began as a way to share regular updates on climate trends has become a trusted reference for policymakers, scientists media, and citizens worldwide. Its consistent and transparent monitoring of our changing climate is now central to our mission. - Carlo Buontempo, C3S Director

Building NEXhub: an infrastructure for the future of IFS experimentation

Paul Burton, Paolo Battino, Michael Sleight, 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 (Sleight 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 PreplIFS software surfaced. Developed in 1999 to facilitate the configuration of the increasingly complex IFS system (Wedi et al., 1999), PreplIFS 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 PreplIFS system, provide additional functionality and, in the longer term, improve other parts of the IFS developer workflow.

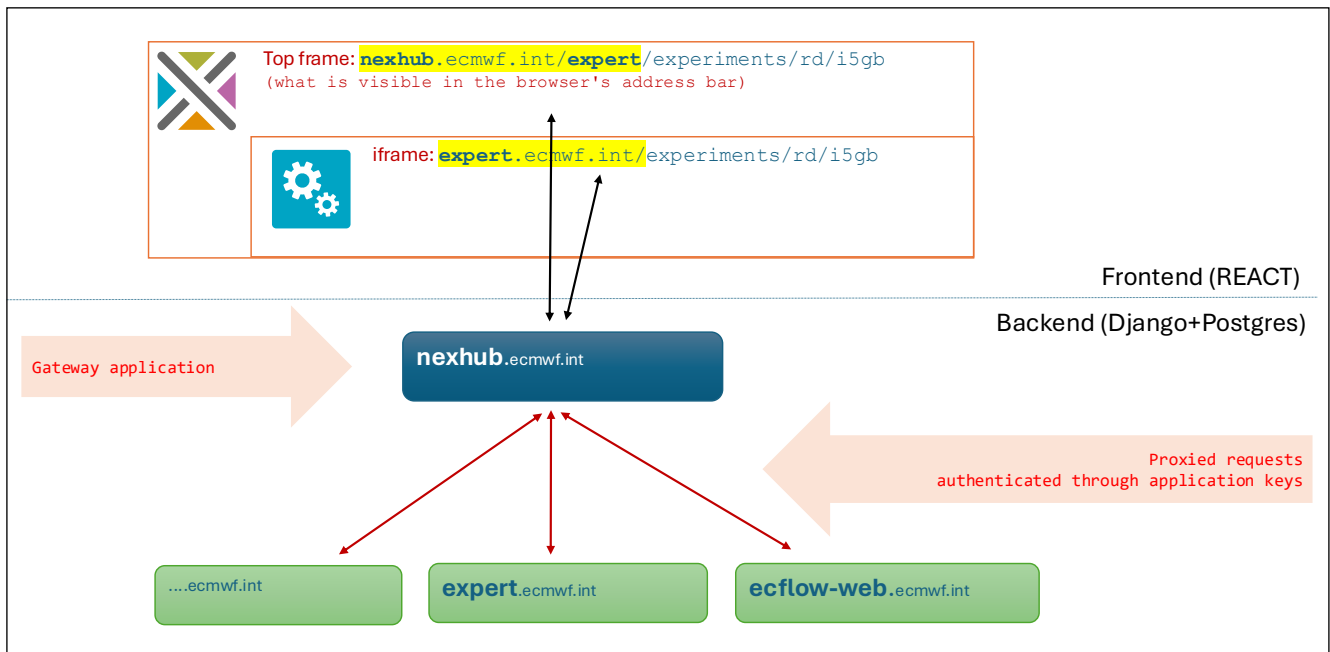


FIGURE 1 Diagram depicting how the application running on nexhub.ecmwf.int acts as a gateway to other applications.

Multiple applications with a seamless user experience

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.

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 PreplIFS, 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 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.

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.

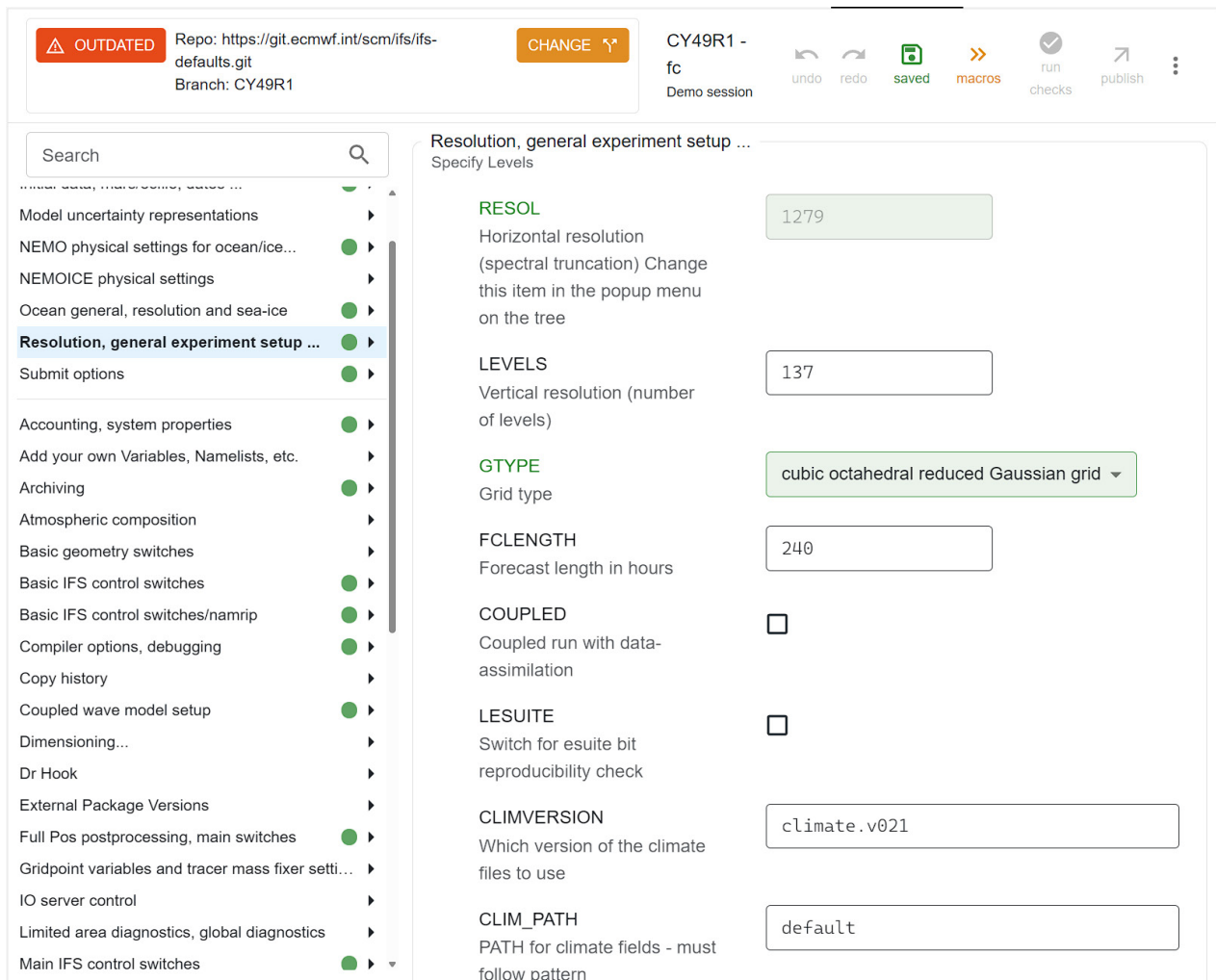


FIGURE 2 Screenshot of the ExpERT user interface, with panels of related variables on the left side and corresponding variable lists on the right, a similar layout to PreplIFS.

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 PreplIFS

Command line tools are provided that allow users to move PreplIFS 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.

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.

The screenshot shows the 'ecFlow Web Viewer' interface. On the left is a tree view of tasks, with 'oopsvar' selected under the 'io1o' task. The main panel displays a table of configuration variables for the selected task.

Name	Value	Inherited from
LSCREEN_IN_OOPS	true	-
mode	trajmin	-
PRIORITY	71	-
TASK	oopsvar	-
ECF_JOB	/var/cache/ecflow/rd/dab/10/an/main/lw12/an/4dvar/uptraj_0/oopsvar.job1	-
ECF_SCRIPT	/var/cache/ecflow/rd/dab/10/an/main/lw12/an/4dvar/uptraj_0/oopsvar.ecf	-
ECF_JOBOUT	/ec/1ws1/sb/log/rd/dab/10/an/main/lw12/an/4dvar/uptraj_0/oopsvar.1	-
ECF_TRYNO	1	-
ECF_RID	20885328	-
ECF_NAME	/dab/10/an/main/lw12/an/4dvar/uptraj_0/oopsvar	-
ECF_PASS	p/2YoaHF	-
FAMILY1	uptraj_0	uptraj_0
FAMILY	io1o/an/main/lw12/an/4dvar/uptraj_0	uptraj_0
uptraj	0	uptraj_0
I_EXTRACT		uptraj_0
USE_HUGEPAGE	False	4dvar
THREADS	16	4dvar
OCPERT	0	4dvar
NPES_CCMA	%NPPOOLS%	4dvar
NPES	%NPES_AN%	4dvar
NEMOVAR_NPROC	6	4dvar
NEMOVAR_NPROCX	8	4dvar
NEMOVAR_NPROC	48	4dvar
HYPERTHREADING	False	4dvar
YMD	20220601	lw12
YMD_JULIAN	2459732	lw12
YMD_DOW	3	lw12
YMD_DD	1	lw12
YMD_MM	6	lw12
YMD_YYYY	2022	lw12

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

ECMWF publications

(see www.ecmwf.int/en/research/publications)

Technical Memoranda

- 931 **Haiden, T., M. Janousek, F. Vitart, F. Prates, M. Maier-Gerber, C. Wing Yi Li, M. Chevallier:** Evaluation of ECMWF forecasts. *September 2025*
- 930 **Janssen, P.** Review of Freak Wave Research at ECMWF. *August 2025*
- 929 **Zaizhong, M., N. Bormann, K. Lean, D. Duncan, E. Berbery & S. Kalluri:** Forecast impact assessment of SMBA using the EDA method. *August 2025*

ESA or EUMETSAT Contract Reports

Duncan, D., N. Bormann, M. Dahoui & M. Crepulja. Assessment of the Arctic Weather Satellite in NWP. *September 2025*

EUMETSAT/ECMWF Fellowship Programme Research Reports

Scanlon, T., P. Browne, A. Geer & N. Bormann: Improving the Ocean Temperature in a Coupled Atmosphere-Ocean System using Microwave Imager Observations. *September 2025*

ECMWF Calendar 2025

Oct 27–31	Training course: Machine learning for weather prediction
Oct 27	Policy Advisory Committee
Oct 28	Finance Committee
Nov 5–7	Digital Twin Co-Design Workshop
Nov 10–14	Training course: Hands-on introduction to NWP models
Nov 28	Destination Earth Coordination Group
Dec 1–3	ECMWF's 50th anniversary events in Reading, UK
	Dec 1-2 Member States machine learning pilot project meeting
	Dec 3 Showcase of European capabilities in machine learning in weather forecasting
	Dec 3 50th anniversary gala evening
Dec 3–4	CAMEO project final General Assembly
Dec 4–5	Council
Dec 18	AI Weather Quest SON Awards Webinar

ECMWF Calendar 2026

Feb 2–5	Training course: Use and interpretation of ECMWF products
Feb 23–27	Training course: Machine learning and Destination Earth
Mar 2–6	Training course: Parametrization of subgrid physical processes
Mar 16–20	Training course: Data assimilation and Machine Learning
Mar 23–27	Training course: EUMETSAT/ECMWF NWP-SAF satellite data assimilation
Apr 13–17	Training course: Numerical methods for weather prediction
April 13–17	5th ECMWF–ESA Machine Learning Workshop
April 30	Finance Committee (virtual)
Jun 16–17	Council
Oct 5–7	Scientific Advisory Committee
Oct 8–9	Technical Advisory Committee
Oct 20–21	Finance Committee
Oct 21	Policy Advisory Committee
Dec 8–9	Council

Contact information

ECMWF, Shinfield Park, Reading, RG2 9AX, UK

Telephone National 0118 949 9000

Telephone International +44 118 949 9000

ECMWF's public website www.ecmwf.int/

E-mail: The e-mail address of an individual at the Centre is firstinitial.lastname@ecmwf.int. For double-barrelled names use a hyphen (e.g. j-n.name-name@ecmwf.int).

For any query, issue or feedback, please contact ECMWF's Service Desk at servicedesk@ecmwf.int. Please specify whether your query is related to forecast products, computing and archiving services, the installation of a software package, access to ECMWF data, or any other issue. The more precise you are, the more quickly we will be able to deal with your query.



Newsletter | No. 185 | Autumn 2025

European Centre for Medium-Range Weather Forecasts

www.ecmwf.int