ECMWF | EUROPEAN CENTRE FOR MEDIUM-RANGE WEATHER FORECASTS

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ECMWF STRATEGY 2025–2034

Contents

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Foreword

ECMWF Council delegates
This Strategy was approved by the ECMWF Council at its session in Reading, UK, in December 2024.

As President of the Council for the European Centre for Medium-Range Weather Forecasts since 2023, it has been a privilege to oversee the development of our new strategy for the next ten years, and to see the commitment from all staff and Member and Co-operating States to ensuring that ECMWF continues to develop strongly and delivers with excellence.

It is now my pleasure to introduce this ECMWF Strategy 2025–2034, where you will find a renewed commitment to work with and for our community, and to maintain ECMWF's leading position. This means that together we will continue to deliver world-leading monitoring and predictions of the Earth system enabled by cutting-edge physical, computational and data science.

ECMWF delivers a critical component of preparedness and citizen wellbeing for member nations in the face of severe weather exacerbated by climate change, and provides vital weather and climate information to a global community. In the coming decade, we know that the impacts of climate change on society will only worsen, while we will face pressures from stressed economies, geopolitical instability and rapidly evolving technology. Collective action, rooted in robust numerical weather prediction science, is essential to prepare Member States and others internationally to face these challenges.

This strategy ensures that ECMWF will strive constantly to bring the best science to improve and extend weather forecasting in the medium range. We will collaborate with all our members to ensure we are at the cutting edge of realising the potential of machine learning techniques to improve our forecasts. ECMWF will operate seamlessly across our sites as a responsible organisation which looks after our people and the planet.

I am grateful for all the support over almost a year of discussions, which have included all committees as well as the 35 Member and Co-operating States and ECMWF management, and the insights from across the European Meteorological Infrastructure. Together we share a vision of the strength of a common goal which will contribute to a safe and thriving society for all.

Professor Penny Endersby CBE FREng
President of ECMWF Council

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1. Introduction

The needs of society for accurate weather and climate monitoring information have never been greater. Reliable advance warning of weather events is essential for the protection of lives and properties, and environmental monitoring is a crucial input for finding appropriate adaptation and mitigation strategies.

As part of the European Meteorological Infrastructure, which offers an invaluable collaborative environment on which the strength of the meteorological community is built, ECMWF works extremely closely with the National Meteorological Services (NMSs) of its Member and Co-operating States and with EUMETSAT to deliver its mission:

Mission: Deliver global numerical weather predictions focusing on the medium range and monitoring of the Earth system to and with our Member States.

The global predictions produced complement the capabilities of the NMSs themselves, and thus ultimately help them to fulfil their roles and provide a better service for the European (and global) society. Accelerating scientific and technology advances have blurred to some extent the boundaries between knowledge domains so that the achievement of this mission today requires that the wider context of environmental monitoring and forecasting at different time scales is addressed, with a significant support from computational and data sciences. Furthermore, the delivery of the mission itself could only be achieved with strong collaborations, as encapsulated in our Vision:

Vision: World-leading monitoring and predictions of the Earth system enabled by cutting-edge physical, computational and data science, resulting from a close collaboration between ECMWF and the members of the European Meteorological Infrastructure, will contribute to a safe and thriving society.

The ambition is to maximise the benefits of initialised seamless predictions exploiting the Earth system approach and the synergies with the EU Copernicus and Destination Earth programmes, with a central focus on ensemble medium-range weather forecasts and improving the skill and usefulness of forecasts for further ahead (e.g. sub-seasonal). Delivery of the vision is reliant on collaboration with our Member States, a world-class supercomputing capability, a diverse portfolio of activities necessary to deliver our mission, talented and motivated staff, the fostering of a vibrant international community by collaborating with the leading experts in their fields in all of our Member States and contributing to raising the collective expertise. It is accompanied by an ambitious net zero strategy, and an ongoing commitment to the overarching values of collaboration, integrity and passion.

While there is much continuity in the overall mission and vision of ECMWF, it is of course necessary to recognize that we live in a fast-changing world. As well as geo-political uncertainty, the traditional meteorological landscape is being challenged by the rise of new players at various points in the value chain e.g. provision of observations, prediction systems and services. At the same time, technological advances present

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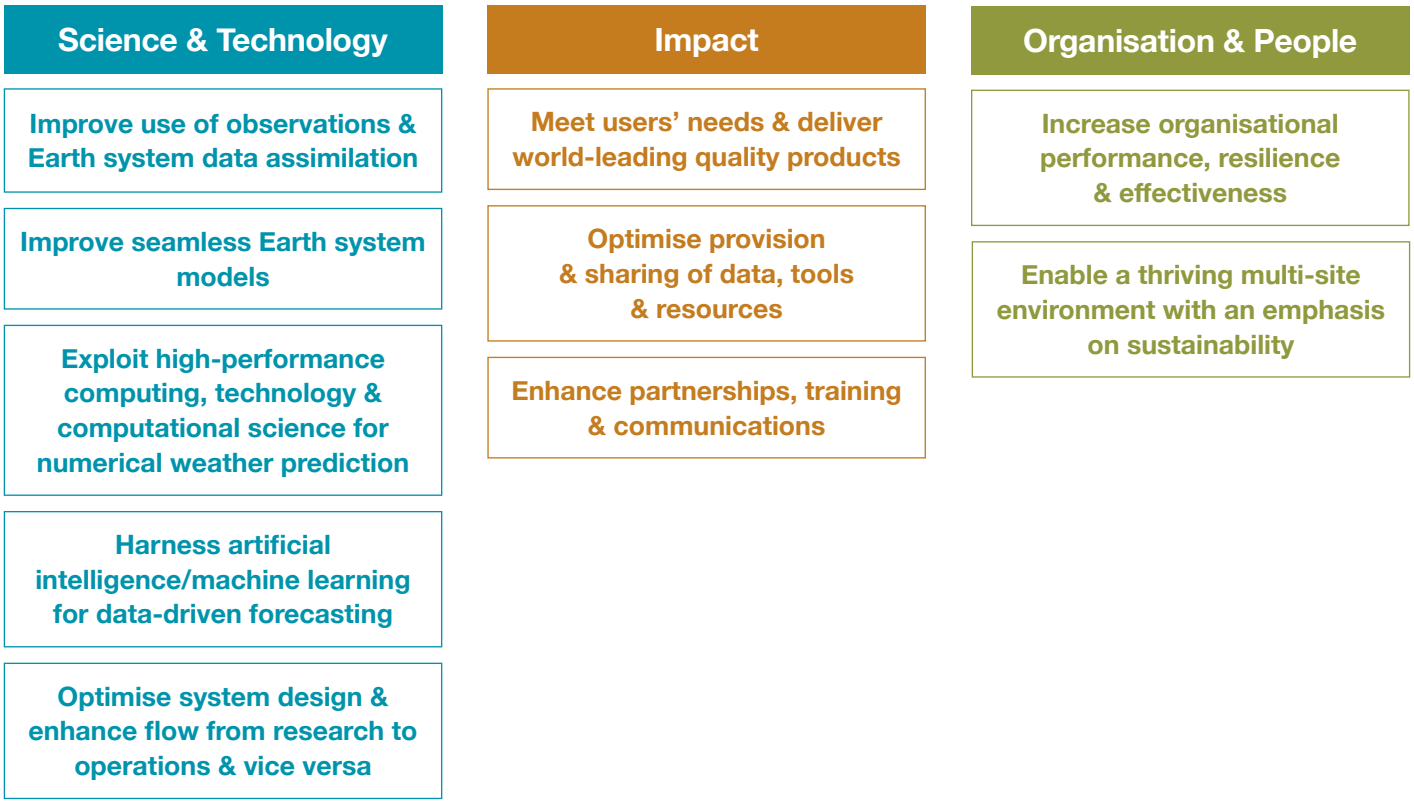

Figure 1
Framework of the strategy 2025–2034.

both opportunities and challenges. For example, cloud computing allows new approaches for handling data (e.g. as done with EUMETSAT and the EMI with the European Weather Cloud) and evolving supercomputer architectures offer the promise of more performance for lower financial and energy cost, but require major software development to exploit them efficiently. Perhaps most striking of all is the rapid rise in the application of artificial intelligence and machine learning in the meteorological field. The previous ECMWF strategy anticipated this with the introduction of a new Strategic Action in this area, but progress has been even faster than expected, with data-driven models already at a maturity where we can confidently expect them to play an important part in operational prediction.

The overarching framework of the strategy consists of three pillars: Science and Technology, Impact and Organisation and People (see Figure 1). These pillars are underpinned by 10 strategic actions. Compared to the previous strategy, it is at the level of the strategic actions that most of the changes of emphasis in response to the changes, opportunities and challenges highlighted above can be seen. However, it is possible to draw out some common threads.

First of all, collaboration has always been at the heart of ECMWF, but it will be more important than ever as the EMI seeks to find a way through this time of rapid change in a way that delivers most to society. For instance, to respond to fast technological change, ECMWF will see provision and joint development of software tooling as an increasing part of the value provided to its Member and Co-operating States, helping them to efficiently fulfil their mandates. Examples could include the infrastructure behind machine learning models (as part of the pilot project in that area), and tools for code adaptation and forecast calibration.

Secondly, ECMWF will continue to engage in major EU programmes such as Copernicus and Destination Earth which provide fantastic opportunities. ECMWF will strive to maximise the benefits to its Member States and to the EU and to achieve the most ambitious goals of ECMWF and its EMI partners by developing and exploiting their collective capabilities to their maximum extent. Such offering will be co-designed to ensure that it fully takes advantage of, complements and enhances the existing service landscape.

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Thirdly, while the Strategic Actions encapsulate ECMWF's main directions for the coming years, it has to be acknowledged that there is more than usual uncertainty. For this reason, the strategy is deliberately high-level, and it will be crucial that in its implementation, flexibility and agility are demonstrated and indeed are seen as virtues. ECMWF and the other members of the EMI have already together shown their ability to do just this with their recent response to machine learning developments. One of the main foci in the coming years will be further clarifying exactly how far machine learning approaches can go, with a view to ensuring the optimal mix of machine learning and physics-based approaches in operational ensemble systems. The evolving directions to take and priorities will be regularly reviewed with ECMWF's committees.

It is possible to imagine a range of scenarios. At one end of the spectrum, fully data-driven models provide a useful operational additional forecasting tool run alongside NWP systems (that themselves increasingly become hybrids of physical and data-driven methods). Going further, real-time operational predictions might be largely or entirely delivered through data-driven models but with continued reliance on data assimilation systems and reanalyses. In this scenario the physics-based models would be used within the data assimilation and, non-real-time, for understanding and the creation of training datasets. Most radically of all, learning directly from observations might, for some applications, provide a route to generate products directly from observations, whose operational feasibility would need to be assessed in an agile way. Common to all these scenarios is a need for ECMWF to embrace innovation, partnership, investment in data and infrastructure and a willingness to reimagine existing workflows and processes and, by so doing, provide the most valuable services to its Member and Co-operating States and wider society.

ECMWF in 2035

- Innovating at the cutting edge of physical, computational and data science for environmental monitoring and prediction.
- Delivering forecast tools and products of unprecedented quality, exploiting data-driven methods anchored on physics-based modelling.
- Integrated in and collaborating with the wider European meteorological community to deliver maximum value to society.

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2. ‘Science and Technology’ strategic actions

The ‘Science and Technology’ strategic actions cover enhancements in the exploitation of observations, data assimilation, modelling and exploitation of new technologies, computational science and operational processes. Note that the application of machine learning within physics-based assimilation and modelling systems is described within those strategic actions, while fully data-driven methods are described in their own strategic action.

2.1 Improve use of observations & Earth system data assimilation

- Better use of existing data (use of satellite data over all surfaces, higher resolution, extending windows, etc.)
- New instruments, new space, Internet of Things
- Design of the global observing system
- New thrust of data assimilation to improve models

Improvements to the data assimilation and use of observations remain crucial for improving forecast (and analysis/reanalysis) quality and gaining the most value from European investments in space. For the foreseeable future 4D-Var will remain at the heart of ECMWF’s efforts (although the recent adoption of the Object-Oriented Programming System, OOPS, provides flexibility to revisit this choice of core algorithm if required). However, there will certainly be increasingly ambitious efforts to integrate machine learning approaches in a hybrid context (e.g. to use observations that are difficult to use or to emulate some aspects of the ensemble of data assimilations to reduce its cost). Increasing the resolution of 4D-Var and using extending windows will make better use of the observations, with the latter also providing the possibility of having more frequent analyses and suite simplification. Efforts will also continue to be devoted to develop the techniques used to initialize Earth system components such as the land, ocean, ice and atmospheric composition, moving as appropriate towards the ensemble-variational approach used for the atmosphere. In parallel, and as reported in Section 2.4, ECMWF will explore with partners the potential for a more radical attempt to use machine learning directly on observations.

Additionally, a major new thrust in this strategy period will be the use of data assimilation and observations, not just to provide initial conditions for models – but also to directly improve the models themselves. This will be done by learning key uncertain model parameters that are known to affect forecast quality (e.g. some of those associated with the land surface) and by providing information on model error which can then, through machine learning of the error as a function of meteorological conditions, be applied online as a correction term in the model. The data assimilation system will also continue to be extended to estimate emissions, both to improve air quality forecasts and to provide anthropogenic carbon dioxide and methane emissions as part of the CO2 Monitoring and Verification Support capacity (CO2MVS). Furthermore, the approach used for composition assimilation will become

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increasingly multi-variate, in order to take maximum advantage of the available observational data.

Notwithstanding huge successes over the years in improving the use of satellite data, there remain huge opportunities to do more. The last ECMWF strategy launched a long-term activity to move from an 'all-sky' to an 'all-sky and all-surface approach' and hence address the significant under-exploitation of satellite data which has a marked sensitivity to uncertain surface characteristics. Progress has been encouraging (e.g. through increasingly coupled assimilation approaches, and through the use of machine learning to estimate otherwise unknowable surface parameters) and efforts in this direction will be continued and enhanced. As a further strand of activities to further exploit satellite data, ECMWF will also work on techniques to enable assimilation of visible, lidar and radar data, in close collaboration with partners (e.g. through the EUMETSAT NWP-SAF).

As well as better exploiting existing data, ECMWF will strive, with its partners (e.g. Member and Co-operating States, EUMETSAT and ESA), to gain maximum benefits from new observations. This will include seeking to fully exploit the major investments made in EUMETSAT systems (e.g. MTG, EPS-SG and other future missions), Sentinels, Copernicus Expansion Missions and ESA Earth Explorers (with a focus on EarthCARE). Additionally, developments will ensure that the infrastructure is sufficiently agile to be able to obtain, exploit and monitor new-space opportunities (e.g. large constellations of small satellites).

Efforts will continue to be made to optimize the use of conventional data (e.g. with increased coverage of MODE-S aircraft data) and, in a close collaboration with its Member and Co-operating States and EUMETNET, to assess the potential of IoT data for global NWP. More generally ECMWF will continue to play a central role, using the tools at its disposal to demonstrate the value for global weather prediction of existing observations and predict the value of future observations, in working with space agencies and WMO (e.g. SOFF) to refine the vision for the long-term evolution of the global observing system. In close partnership with WMO, ESA and EUMETSAT, ECMWF will also work with the wider meteorological community to make the case for the continued protection of crucial frequency bands from radio frequency interference.

2.2 Improve seamless Earth system models

- Driving down systematic model errors and improving teleconnections through physics developments and hybridisation of physics-based and data-driven methods (e.g. more aggressive optimisation and online correction)
- Km-scale (convection, microphysics, non-hydrostatic and Finite Volume Module, etc.) for operations and training datasets
- Earth system development (e.g. emissions, aerosols) as end in themselves and to improve performance of coupled system

ECMWF uses the Earth system model within the data assimilation cycle for ensemble predictions from medium-range to seasonal and to provide boundary-conditions for limited area models. Furthermore, it provides and collaborates with others (EC-Earth, DestinE climate digital twin consortium) who take the Integrated Forecasting System (IFS) and further develop it for climate modelling, and significant parts of the code are shared with some of the limited area modelling community. For all of these applications, the accuracy of the model is paramount. ECMWF will therefore continue to work with partners in its Member States to drive down errors in the physical model and improve the representation of model uncertainty, with a particular focus on user-relevant metrics including near-surface wind, temperature and precipitation and on improving the skill of sub-seasonal predictions (e.g. through improved representation of teleconnections).

Additionally, ECMWF will seek to further accelerate progress by investing significantly in a hybrid approach, whereby the strengths of physics-based modelling are augmented with approaches from

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data-driven modelling. This will include more aggressively seeking to optimize uncertain model parameters (through the data assimilation or Bayesian optimization) and also to 'learn' model error and apply it online in the model.

ECMWF will endeavour to exploit kilometre-scale global modelling, taking full advantage of Destination Earth and of the experience and expertise available in its Member State community. Key challenges to be overcome include optimizing the representation of partially resolved processes (e.g. convection) and introducing more advanced representations of other processes (e.g. TKE scheme for turbulence and double moment microphysics), and demonstrating, in addition to already improved local detail, that the enhanced resolution is beneficial for large-scale evolution. Efforts will continue to assess at what point the extra costs associated with a non-hydrostatic representation justify the increased costs and, for the longer term, ECMWF will develop the Finite Volume Module (FVM) to provide a new non-hydrostatic core that is locally conservative and highly scalable. As well as direct relevance through all of these efforts leading to the operational implementation of kilometre-scale models, it is important to note that they also have a second route to impact, through being used to provide enhanced high-resolution global datasets for the training of data-driven models.

Efforts will continue to improve the modelling of Earth System processes beyond the atmosphere, partly because some aspects are important products in their own right (e.g. air quality, hydrology, fire danger) but especially as they impact the evolution of the coupled system. For the ocean, the benefits of higher resolution (1/12 degree) will be investigated. For the CAMS system, priorities will include improved modelling of emissions and the development and testing of a modal aerosol scheme. ECMWF will also exploit the dual grid capabilities which enable different processes to be modelled at different resolutions. This will allow scientific advances which would be otherwise unaffordable, notably upgrading the simple climatological representation of aerosol used for NWP-seasonal to use the much more advanced (but expensive at full resolution) scheme used in the CAMS system.

2.3 Exploit high-performance computing, technology & computational science for numerical weather prediction

- Resilient, energy-efficient, cost-effective resources for ECMWF and Member and Co-operating States, taking into account changing requirements (e.g. GPUs)
- Workflows and suites to use distributed resources (Digital Twin Engine)
- Flexible code adaptation for future architectures

HPC, cloud-based and data centre services are essential in supporting most of ECMWF's strategic actions and are also directly provided to Member and Co-operating States. ECMWF will operate energy-efficient and cost-effective computing resources (HPC, cloud, storage, etc.), data centre services and production processes to enable it to provide the 24/7 resilient operational products and services on which its users depend. Security, including cyber security, will increasingly be taken into account when considering the resilience of ECMWF's infrastructure. The Centre will also continue towards further convergence and integration of its HPC and cloud infrastructures.

ECMWF will investigate technologies enabling the use of distributed resources, allowing it to use the optimum mix (e.g. on and off premise computing, private and public cloud). The ability to take full advantage of such a mix of resources will require a strong focus on cyber-security and continued investments in flexible workflows and suites, as currently being successfully pioneered through the digital twin engine work as part of Destination Earth.

Changes in workloads will require changes to the balance of resource requirements, notably with an increase in GPU availability required for training to sustain the rapid progress in data-driven modelling using machine learning. Additionally, data challenges will increase and ECMWF will,

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with its partners in the EMI and beyond, seek to foster data-centric innovation in order to meet the challenge of processing, storing and analysing increasing volumes of data.

Changes in HPC architectures also bring challenges for the application codes. For the medium-term, the ECMWF strategy remains to develop the existing IFS code, using source-to-source translation to increase capability to leverage a wide range of hardware architectures from multiple vendors. Looking further ahead, whether the use of very large Fortran-based codes will be sustainable 10 or 15 years hence is open to question. Accordingly, ECMWF will also invest in more radically novel approaches based on domain specific languages and the use of Python, initially developing the new Finite Volume Model dynamical core as a trailblazer in this new framework.

2.4 Harness artificial intelligence/machine learning for data-driven forecasting

- Drive innovation in data-driven forecasting (Earth system model and directly from observations)
- Collaboration on techniques and tooling ('ML in a box', Anemoi infrastructure)
- Continuous broad assessment of strengths, weaknesses and potential to inform operational choices

ECMWF elaborated a strategic action on artificial intelligence and machine learning in the previous strategy. Progress in this field has been very rapid – both at ECMWF and beyond – and the adoption of hybrid approaches, combining machine learning with physics-based approaches for assimilation and modelling, is seen as so mainstream and central for the evolution of the assimilation system and model that the plans are now embedded in the relevant strategic actions. The focus here is on furthering the dramatic progress with data-driven models and, more radically, on research into using machine learning techniques directly on observations. Of course, taking advantage of further progress in such areas will require appropriate consideration of issues around data governance and trust and reliability in automated systems.

ECMWF will further develop the techniques – and infrastructure – used by the Artificial Intelligence Forecasting System (AIFS), developing a higher resolution, reliable ensemble system covering increasingly more aspects of the Earth system and which utilizes an increasing variety of training data (e.g. observational data and higher resolution global analyses, reanalyses or forecasts to supplement climate reanalyses such as ERA5, ERA6, and DestinE digital twins). Performance will be evaluated with a wide range of user-relevant metrics (e.g. feature-based as well as traditional scores) in order to give as complete a picture as possible of the strengths and limitations of these methods, and hence inform the overall design of the ECMWF operational system (see Section 2.5). ECMWF will further develop the concept devised in Destination Earth of the 'forecast-in-a-box', as for some users and applications it is likely that sharing the model and initial conditions will be more efficient than producing large amounts of data centrally and then disseminating them. This is just one example of the disruptive changes to current workflows that may be expected over the coming years from machine learning developments.

All of these developments will be done in very close collaboration with ECMWF's Member and Co-operating States (e.g. through the existing pilot project and wider engagement with and contributions to the EUMETNET programme). In particular, many of the algorithmic and infrastructure developments will be common with those required by NMSs (e.g. for even higher resolution regional applications) and the ambition is to co-develop the Anemoi framework to support both rapid development and prototyping and robust operations.

ECMWF will also investigate the possibility of moving beyond reliance on reanalysis for training and traditionally generated initial conditions for initialization, instead looking at directly learning from observations. This represents an exciting frontier science challenge and, while there is no guarantee of what will be possible, significant efforts and an open-minded approach are the most

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likely to deliver what could be another paradigm shift.

2.5 Optimise system design & enhance flow from research to operations & vice versa

- Design of operational system to take best advantage of advances in physics-based, hybrid and data-driven approaches
- Detailed diagnostic studies of operational system
- Robust, flexible and agile infrastructure and processes

It is an exciting time for meteorology, with new developments in data assimilation and (hybrid) modelling, and also the rise of fully data-driven methods all clearly of operational relevance. However, it is also very likely that the optimum operational system to take maximum advantage of these advances for users will be more multi-faceted than hitherto, potentially involving multiple resolutions (e.g. some ensemble members at kilometre-scale and some at coarser resolution) and a mix of (hybrid) physics-based and data-driven members. ECMWF will therefore renew its efforts on system design, using a combination of numerical experimentation and an understanding of user needs to find the optimal combinations of the whole forecasting system. Directions for further advancement will also be strongly informed by predictability studies and detailed diagnostic studies of the performance of the operational systems, where machine learning is envisaged to play yet again an important role to help in understanding model errors.

With the fast pace of developments (e.g. in particular with respect to progress with data-driven models), it will be even more crucial that the infrastructure and research to operations processes are not just robust, but also streamlined and agile. At the same time, for efficiency ECMWF will seek to remove unnecessary complexity, for example by as far as possible aligning the approaches taken for different applications (e.g. Copernicus, Destination Earth digital twins and core NWP). Moving the IFS model (see Section 3.2) to open source will also bring internal efficiency through simplification of the current approach, as well as opportunities for strengthened and streamlined collaboration (e.g. with academia).

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3. ‘Impact’ strategic actions

The positive impact of ECMWF activities is manifested primarily through products of world-leading quality and propagated by means of efficient and resilient operational services. Additionally, ECMWF has a strong role in providing software tooling, while strong collaborations with the EMI provide benefits to all parties.

3.1 Meet users’ needs & deliver world-leading quality products

- Calibrated products taking best advantage of physics-based and data-driven approaches
- Reanalyses for climate monitoring and datasets for ML training; Essential Climate Variables from reanalysis
- Support for climate prediction
- CO2 Monitoring and Verification Support
- Verification and user feedback

The heart of ECMWF will remain the provision of the best quality medium-range predictions to its Member States, driven by their requirements to support their services, with a particular focus on extremes and high-impact weather. Additionally, ECMWF will continue to serve user needs for wider environmental applications including climate monitoring, air quality, floods and fire, and to provide support for climate prediction. The dramatic progress in data-driven approaches to forecasting also makes reanalyses and other training datasets increasingly important in their own right.

As detailed in Section 2.5, the approaches to provide predictions are evolving, with future systems likely to include dual-resolution NWP ensembles (e.g. small high-resolution ensembles complemented by larger lower resolution ones) and potentially large ensembles taking advantage of the dramatic progress in data-driven modelling. Accordingly, ECMWF products will be developed to take advantage of physics-based and data-driven approaches and, where appropriate to best meet user needs, provide combinations of both. Furthermore, with the advent of data-driven models and the application of online model corrections, the distinction between NWP and post-processing is becoming increasingly blurred. ECMWF will therefore provide calibrated products which best meet user needs, and also develop and provide tooling for Member and Co-operating States to apply to enable them to make the best use of ECMWF data in their applications.

Sub-seasonal forecasts will be a major focus, seeking to provide more user-relevant skill in weeks 3 and 4, and long-range products will be extended from seasonal into the second year to take advantage of research progress with respect to El Nino forecasting. In both cases, products will take advantage of a multi-model approach as well as improvements to the ECMWF systems. For longer timescales still, Copernicus and Destination Earth will support global efforts to operationalize different aspects of the provision of climate predictions and projections.

Climate monitoring efforts will be further strengthened, with the delivery of new

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generations of reanalyses (atmosphere, ocean and composition) with higher resolutions and increasing levels of coupling. These reanalysis products will form a coherent offering alongside Essential Climate Variables (ECV) products with, for example, reanalyses used directly to provide ECVs that cannot be observed directly or complementing what can be observed by satellites. In addition to climate reanalyses, ECMWF will produce other datasets (e.g. higher resolution reanalyses or km-scale forecasts) specifically to support the training of machine learning models by ECMWF and its Member and Co-operating States.

The CAMS product portfolio will be further developed, in particular with respect to the representation and communication of uncertainty (e.g. to policy makers). The CO2 Monitoring and Verification Support capacity (CO2MVS) will also provide new information on anthropogenic greenhouse gas emissions to monitor global mitigation actions (e.g. global stocktake and global methane pledge) and support national emission reporting, in coordination with the WMO Global Greenhouse Gas Watch (G3W).

The quality of all products will be monitored through verification and feedback from Member and Co-operating States. This will require the verification techniques and observational datasets to be developed and extended, for example to better capture the value of high-resolution simulations (where ECMWF has much to learn from the expertise of the limited area modelling community in its Member and Co-operating States) and to extend the coverage in Earth system components beyond the atmosphere.

3.2 Optimise provision & sharing of data, tools & resources

- Development of software tooling for and with Member and Co-operating States (e.g. Digital Twin Engine, Anemoi infrastructure for data-driven models)
- Open data and software
- IFS model to open source

To maximize the impact of its products and collaborative activities, ECMWF will continue on its path towards open data, open-source software and on the optimisation of the services for data access, acquisition, storage, generation, manipulation, analysis, integration and delivery.

In respect of the move to open data, it will be formally completed in 2026. However, as volume and number of users increase, ECMWF will continue investigating ways to make their access more efficient.

Traditionally, ECMWF has offered tools for data management, manipulation and reliable delivery mechanisms to its Member and Co-operating States, customers and the wider user base of open and free data and, more recently, cloud services (e.g. European Weather Cloud, Climate Data Store, WEkEO) consistently with the recently agreed software strategy. However, the technological landscape is changing fast, and to fully take advantage of developments in this area, ECMWF and its Member and Co-operating States need to rethink and re-engineer many existing workflows and software infrastructures. Therefore, ECMWF sees an increasing role in developing software tooling, for and with its Member and Co-operating States, to enable all to most efficiently carry out their respective missions. Examples include, but are not limited to, the Anemoi infrastructure for data-driven models, the software components underpinning the Digital Twin Engine and Common Data Store Engine, and source to source translation tools (e.g. Loki) for code adaptation.

Additionally, and in the spirit of ‘open science’ and in order to further collaboration (e.g. with academia) and better serve the scientific community, ECMWF will build on the successful OpenIFS efforts and move to an open-source approach for the whole of the forecast model. ECMWF will also continue to participate actively in the development of community tools such as the EUMETSAT NWP-SAF very fast radiative transfer model RTTOV which is crucial for the exploitation of satellite data.

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3.3 Enhance partnerships, training & communications

- Collaboration with Member and Co-operating States (various mechanisms)
- Principles for strategic partnerships, including EU
- Global collaborations (e.g. WMO, space agencies)
- Training (especially in context of collaboration: 'Training by doing together')
- Enhanced coordinated communication

ECMWF can only achieve the goals of the strategy by collaborating tightly with the broader meteorological community and particularly with the EMI, drawing upon each other's expertise, resources, products, and services. Several innovative activities have been initiated in recent years (cloud services with EUMETSAT, pilot projects, third-party funded activities including Copernicus, Destination Earth and numerous Horizon projects) that have successfully provided the basis for more intensive collaboration. Different frameworks will need to be set up to support a range of new efforts (e.g. via grants) and to make them sustainable, e.g. via optional programmes or participation in EUMETNET programmes. Successful long-term activities (including optional programmes) should eventually be channelled into core activities.

Partnerships will be pursued with the European Commission, in the context of the Copernicus Programme, Destination Earth and possibly other initiatives of mutual benefit to ECMWF, the Member States and the EU. These exciting and innovative programmes enhance and complement the capabilities and activities of ECMWF and the wider EMI, and indeed can only be delivered because of the sustained Member State investment into ECMWF over many decades. Crucial principles for ECMWF's involvement in such activities are that they must be in line with the purpose, objectives and strategy of the Centre, be approved by the Council, they must benefit ECMWF and all its Member States and respect the remits of their authorities, especially the National Meteorological Services. Furthermore, in order to deliver the maximum value and impact from these third-party programmes, and ensure that they build upon and complement the existing service landscape, the EMI should be involved to the largest extent possible in influencing their strategic design, evolution and implementation.

The collaboration with international organisations will be reinforced and in particular: with the WMO (especially in support of Resolution 1, Early Warnings for All and the European State of the Climate), with EUMETSAT, ESA and other satellite agencies aiming at establishing cross-mission partnerships, with UN agencies and other international organisations in areas of common interest and aligned with the objectives of the Convention. Successful current collaborations with national agencies (e.g. NOAA, BOM, CMA, JMA) will be regularly reviewed to ensure reciprocal advantage. New partnerships will possibly need to be established beyond the traditional community to address new and challenging areas of science and technology, especially with the private sector and academia. There is a continued interest from European countries and national agencies worldwide to establish collaborations and formal relationships with ECMWF and responses will take into account the expected mutual benefits. In general, existing and new partnerships will need to be carefully considered in light of possible geopolitical risks.

Training and support will continue to be an essential component of increasing the impact of ECMWF activities on the user community and, in particular, in the context of the collaboration with Member and Co-operating States. A range of means will be used to cover short and long-term needs (courses, workshops, seminars, e-learning, secondments and short visits, learning and supporting by 'doing together').

Strategic communication has been very successful in the period of the current strategy and will continue to be essential to showcase the activities of the Centre and its talented staff through articles, events, and broadcasts, to promote collaborations, increase the reach of products and services and the attractiveness of the organisation for prospective employees and partners. Communication activities could be agreed with Member and Co-operating States to support their national tasks.

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4 ‘Organisation and People’ strategic actions

The ‘Organisation and People’ strategic actions aim to strengthen ECMWF’s structure, enhancing performance, resilience and effectiveness in a multi-site, sustainable and enabling working environment.

4.1 Increase organisational performance, resilience & effectiveness

- Funding aligned with strategic objectives
- Diversity, Equality and Inclusion
- Performance management and staff development

ECMWF will aim to secure sustainable long-term funding to support its strategic objectives. This will involve ensuring that ECMWF continues to provide value for money to its Member and Co-operating States, either from direct contributions or through other potential funding sources including the European Commission, while remaining aligned with the strategy and directives provided by the Member States, and respecting the partnership principles described in Section 3.3.

Recognizing the transformative potential of AI/ML, ECMWF will assess and adapt to its impact on opportunities, staff profiles, and training requirements while mitigating associated risks.

ECMWF will define the best approaches to enhance flexibility, agility, and attractiveness to optimize its workforce, while also taking into account its role, along with others in EMI, in developing staff for the benefit of the whole community. This will involve reviewing and adapting contracting models, advancing initiatives related to Diversity, Equality, and Inclusion (DEI), and implementing robust performance management and development tools. The Centre will put in place a consistent succession strategy. A modernized, harmonized, consistent and coherent social security policy across the different ECMWF duty stations will be pursued to create a cohesive work environment.

4.2 Enable a thriving multi-site environment with an emphasis on sustainability

- Ambitious path to net zero
- #OneECMWF
- New state-of-the art facilities

ECMWF is committed to further identifying, developing, and implementing measures to harmonize its collaborative nature, multi-site operations, and commitment to reducing its carbon footprint. The Centre will devise strategies to ensure connectivity, alignment, and cultural coherence across its three sites. The internal communication function will contribute substantially to ensure that ECMWF continues to work as one cohesive organisation.

ECMWF will continue along the path aiming to achieve net-zero carbon emissions by the year 2030, while being prepared to adapt to emerging environmental challenges, ensuring its environmental plan remains robust and adaptable to future needs.

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ECMWF recognizes the need to review and potentially update its current Enterprise Resource Planning (ERP) system within this Strategy period. This review process will take into account evolving work methodologies and advancements in AI technologies to enhance efficiency in this area.

ECMWF is dedicated to ensuring a smooth and successful transition from its current facilities in Reading and Bonn to the planned buildings. These state-of-the-art facilities will also serve as catalysts for fostering ECMWF's development and leveraging its achievements.

Figure 2
Artist images of current ECMWF premises in Bologna (top) and planned buildings in Bonn (middle) and Reading (bottom).

Bologna: gmp von Gerkan, Marg & Partner;
Bonn: Visualisation: Render Vision; Design: SL/A Architekten;
Reading: © F+G, Member of the SNC-Lavalin Group; Building Design Partnership Ltd; Atkins, Member of the SNC-Lavalin Group; Sanders Studios.

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5. Concluding remarks

ECMWF's core mission remains the provision of the best-quality medium-range weather predictions to our Member States, driven by their requirements, to support their needs and services. ECMWF will also continue to serve user expectations for wider environmental applications, including for climate monitoring, air quality, CO2 monitoring, floods and fires. The dramatic progress in data-driven approaches to forecasting also makes reanalyses and other training datasets increasingly important. In the next decade, this Strategy will address the opportunities offered by scientific and technological advances, including new types of observations, distributed computing environments, and artificial intelligence. Whilst such advances are clearly beneficial, they also require a complete rethink and development of our software, networks, and overall infrastructure. Our increased reliance on digital technologies will place resilience and cyber security at the forefront of our operations. Three main concepts will be at the centre of our work: collaboration, agility and flexibility. The delivery of the Strategy is reliant on strong collaborations with our Member and Co-operating States, a world-class supercomputing capability and a diverse portfolio of activities, which embraces these developments. It requires a drive for excellence, with talented and dedicated staff focused on finding solutions to the many challenges ahead. Together with leading experts from our Member States, this will create a vibrant international community that will impact numerical weather predictions for the benefit of society. Finally, the strategy is rooted in an ambitious net zero plan and an ongoing commitment to staff development and fostering a dynamic culture across ECMWF's three sites.

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