STRATEGY 2016–2025

THE STRENGTH OF A COMMON GOAL

Austria Zentralanstalt für Meteorologie und Geodynamik (ZAMG)

Belgium Royal Meteorological Institute of Belgium (RMI/KMI)

Croatia Meteorological and Hydrological Service of Croatia (DHMZ)

Denmark Danish Meteorological Institute (DMI)

Finland Finnish Meteorological Institute (FMI)

France Météo-France

Germany Deutscher Wetterdienst (DWD)

Greece Hellenic National Meteorological Service (HNMS)

Iceland Icelandic Meteorological Office (IMO)

Ireland Met Éireann

Italy Ufficio Generale Spazio Aereo e Meteorologia (USAM)

Luxembourg Air Navigation Administration

The Netherlands Royal Netherlands Meteorological Institute (KNMI)

Norway Norwegian Meteorological Institute

Portugal Portuguese Sea and Atmosphere Institute (IPMA)

Serbia Republic Hydrometeorological Service of Serbia

Slovenia Meteorological Office, Slovenian Environment Agency (SEA)

Spain Agencia Estatal de Meteorología / State Meteorological Agency (AEMET)

Sweden Swedish Meteorological and Hydrological Institute (SMHI)

Switzerland Federal Office of Meteorology and Climatology MeteoSwiss

Turkey Turkish State Meteorological Service

United Kingdom Met Office

Member States as of January 2016 and their national meteorological and hydrological services

STRATEGY 2016–2025

THE STRENGTH OF A COMMON GOAL

CONTENTS

FOREWORD

Forty years ago, the Convention creating ECMWF came into force. A group of European nations, sharing the vision that collaboration in weather science would benefit citizens and economies, pooled their resources together and created what is to this day a unique numerical weather prediction centre. Developing ECMWF as both a research institute and a 24/7 operational centre, they set the bar very high, and simultaneously built the foundations for a successful mission-driven international organisation.

Today, as a growing group of nations looking back at what has been achieved, we cannot help but take pride in the way yesterday's vision has become today's reality. ECMWF is recognised as leading the world in global numerical weather prediction (NWP) innovation and practice. Its forecasts, which are acknowledged worldwide as being of the highest quality, are today as accurate for 6 days ahead as they were for 3 days ahead 30 years ago. The spatial resolution of these forecasts is today more than 20 times finer than it was when we began. The Centre's predictions reach the national meteorological services (NMSs) of 34 Member and Co-operating States every day, as well as international partners around the world. We consistently support weather services and via WMO programmes enable some of the poorest countries in the world to have access to life-critical data.

The basis of our Strategy for 2016–2025 can be summarised in two words: more collaboration. Looking at what collaboration has already achieved, we know it is the only way to succeed in the ambitious path laid out in this Strategy. The partnership between ECMWF's Member and Co-operating States sets the direction of travel. It supports the Centre's staff, who represent over 30 countries, enables work with independent experts around the world who share their knowledge, experiences, and insight, and links us with space agencies that make possible critical measurements. More collaboration will make it possible to tackle the next big challenges, to predict the range of possible scenarios and the likelihood of occurrence of high-impact weather up to two weeks ahead, large-scale patterns and regime transitions up to four weeks ahead, and global-scale anomalies up to a year ahead.

Is the vision the same as it was when the Centre started? No, because the science of global weather prediction has advanced so much. For example, when ECMWF started, the prospect of using over 40 million observations a day from over 70 satellite instruments was hardly imaginable. Nor did we have the ability to provide forecasters with a reliable estimate of the confidence in our predictions via ensemble prediction.

Despite how much has been accomplished, it is still nowhere near enough. But forewarned is forearmed and with improved forecasts fewer people will lose their lives because of extreme weather events, fewer livelihoods will be destroyed, and national and regional economies will suffer less paralysis following flooding, heat waves, cold spells, tropical cyclones, and windstorms.

This Strategy has been developed collaboratively and will help deliver forecasts increasingly at a human scale. It will improve longer range predictions over Europe, and help give those who need them – emergency services, public authorities and citizens – the tools to make decisions informed by the level of confidence in each of our predictions.

We have advanced the science and improved the forecasts, but much more needs to be done and we are ready to take on the challenge.

Gerhard Adrian
President, ECMWF Council

ECMWF Council and directors December 2015

EXECUTIVE SUMMARY

GOALS BY 2025

To provide forecast information needed to help save lives, protect infrastructure and promote economic development in Member and Co-operating States through:

Research at the frontiers of knowledge to develop an integrated global model of the Earth system to produce forecasts with increasing fidelity on time ranges up to one year ahead. This will tackle the most difficult problems in numerical weather prediction such as the currently low level of predictive skill of European weather for a month ahead.

Operational ensemble-based analyses and predictions that describe the range of possible scenarios and their likelihood of occurrence and that raise the international bar for quality and operational reliability. Skill in medium-range weather predictions in 2016, on average, extends to about one week ahead. By 2025 the goal is to make skilful ensemble predictions of high-impact weather up to two weeks ahead. By developing a seamless approach, we also aim to predict large-scale patterns and regime transitions up to four weeks ahead, and global-scale anomalies up to a year ahead.

ECMWF's purpose today is the same as it was at its creation, laid out in its Convention, **to develop a capability for medium-range weather forecasting and to provide such weather forecasts to the Member and Co-operating States**. ECMWF develops, and operates on a 24/7 basis, global models and data assimilation systems for the dynamics, thermodynamics and composition of the Earth's fluid envelope and interacting parts of the Earth system.

Challenges and opportunities

The past few years have seen advances in science and technology open up the potential for extending how far into the future we aspire to predict various aspects of the weather, but they have also illustrated the increased dependency of society on accurate and reliable weather prediction. They have seen good forecasts and, occasionally some less so, but they have also highlighted a direction of travel towards a comprehensive Earth system approach.

We believe that the next ten years should be about building on the advances already made in data assimilation, model development, uncertainty estimation and coupling of Earth system components in order to take a bold step towards improved numerical weather prediction. They will also need to be about tackling the major computing challenges facing the meteorological community, namely big data and computational efficiency.

EARTH SYSTEM FOR WEATHER PREDICTION

In the context of weather prediction, the term 'Earth system' refers to the Earth's fluid envelope and its interactions with its boundaries. Earth system components such as the atmosphere, the oceans, sea ice, and the continental land surface have a significant impact on the weather. Modelling their interactions with each other can therefore lead to improved weather forecasts. For example, using ocean modelling in the Integrated Forecasting System has led to improved predictions in the medium range as well as at monthly and seasonal timescales. Taking an Earth system approach means representing the interactions between as many Earth system components as required, at the necessary level of complexity, to achieve our future goals.

A roadmap to 2025

Advancing weather science and improving numerical weather prediction to meet these goals over the life of the next Strategy will require a balance of talent and technology which will rely on:

- Attractive working terms and environment to attract and retain the required talent
- ECMWF inspiring and attracting international scientific and computing collaboration across the Member States and beyond
- A powerful, energy-efficient and resilient infrastructure, including a high-performance computing facility, systematically seeking to minimise its environmental impact
- Scalable and efficient modelling and processing codes that encompass a comprehensive Earth system approach

Serving Member and Co-operating States and the wider community

The Strategy will also see an enhancement of the services that ECMWF develops and provides for its Member and Co-operating States, and the wider meteorological community, especially in the areas of:

- Dedicated supercomputer capacity and specialist software for members
- A comprehensive meteorological data archive available within and outside of ECMWF
- Global reanalyses and re-forecasts
- Advanced training in Earth system modelling and forecasting
- An enduring partnership with the World Meteorological Organization (WMO), allowing the poorest nations in the world access to life-critical data
- Initial and boundary conditions for regional fine-scale weather prediction models as required by members of the Optional Programme
- Additional operational activities, such as atmosphere monitoring, flood forecasting and climate change services, supported by third parties

Whilst this Strategy sets the goals for ten years ahead, it will be refreshed after five years and this will enable it to evolve in line with science and technology. In addition, the implementation plan for this Strategy, covering a rolling four-year period (the Four-Year Programme of Activities), will be updated every year and reviewed annually by ECMWF's advisory committees and Council. This enables ECMWF to prioritise the implementation according to circumstances such as the availability of resources and the progress in research and development.

CONTEXT: CHALLENGES AND OPPORTUNITIES

The size of the challenge

People are increasingly vulnerable to weather and other aspects of the natural environment because of population density, the regions where people live and a changing climate. The need for weather information is pervasive, affecting people, businesses, policy-makers, governments and society at large. As weather forecast skill has advanced, the value of this information has increased and consequently expectations of further improvements have grown tremendously. Not only are weather forecasts saving lives and limiting property damage, but such prior information also presents many sectors of the economy with opportunities by enabling them to manage weather- and climate-related risks. These opportunities will arise from a full integration of the science, numerical predictions, and user requirements.

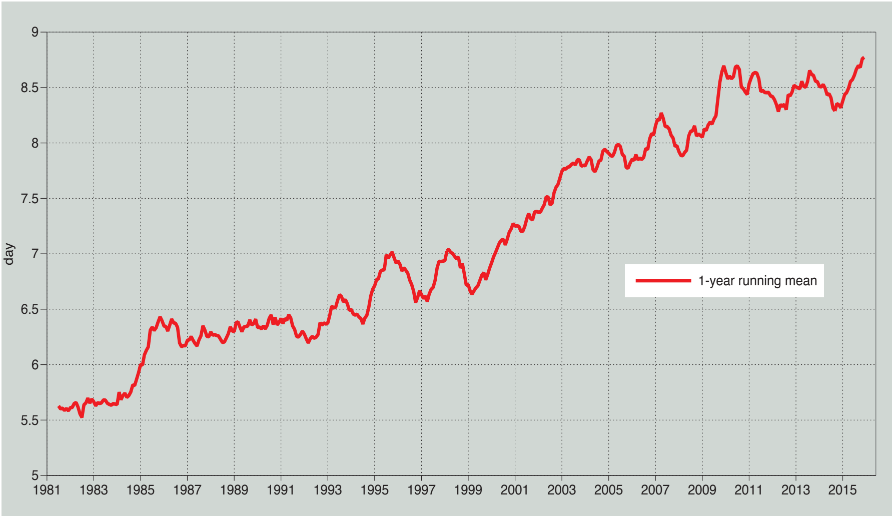
ECMWF is a success story of European scientific and technical co-operation; today its 34 Member and Co-operating States – twice the original number – work together on numerical weather prediction (NWP). ECMWF's approach is one of partnership; it cannot deliver this Strategy without co-operation. ECMWF is part of the European meteorological community, which has grown substantially since the Centre was established in 1975 and it continues to develop, so that the co-operation is built upon complementarity. ECMWF works very closely with the national meteorological services that are responsible for providing warnings of severe weather and delivering weather services to their users. ECMWF supports the national meteorological services by providing them with global predictions that complement their own NWP capabilities. ECMWF's Member and Co-operating States have diverse meteorological requirements and expertise. As the context evolves, ECMWF acts as a lynchpin focussing not only on requirements common to all Member States but also catering for individual needs.

The volume and diversity of Earth observations from space continues to increase substantially. ECMWF depends critically on the high quality satellite observations provided by EUMETSAT, and works closely with it to optimise the use of operational satellites. ECMWF also collaborates with ESA on evaluating new research satellite missions. ECMWF has a strong relationship with many space agencies in WMO's Coordinating Group for Meteorological Satellites (from China, Japan, India and the United States in particular), as well as with national providers of conventional observations. This will continue to allow ECMWF to play an active role in helping to define user requirements for new observations in the WMO Integrated Global Observing System, helping Space Agencies to plan future programmes.

Academic research in weather and climate science in Europe and elsewhere has expanded hugely. Private-sector weather forecasting has also developed significantly, as has the use of weather forecast (and environmental) information by businesses. New opportunities exist for ECMWF to form partnerships with colleagues and organisations worldwide. Notably the WMO provides the framework for many collaborative activities both in research and in operational weather prediction and ECMWF thereby plays a significant global role, not least in contributing to WMO's strategic goals.

WORKING WITH NATIONAL METEOROLOGICAL SERVICES

ECMWF works with the European national meteorological services and provides them with vital global NWP data and support. This partnership is multi-faceted and encompasses research, numerical weather predictions, supercomputing, and training. For example, ideas coming from Member States can be developed jointly with ECMWF if the Centre has relevant resources to offer. Equally, ECMWF can lead on an initiative and work with those Member States with relevant expertise or interests to jointly develop solutions, as in the Scalability Programme. The Centre is a shared European resource providing an efficient and high quality service to its Member and Co-operating States.



Evolution of medium-range ECMWF forecast skill over the past 35 years. The curve shows the number of days that forecasts provide useful information. This is defined as the day beyond which the Northern hemisphere, 500 hPa geopotential height anomaly correlation drops below 60%.

When ECMWF was inaugurated in 1975, global NWP was in its infancy and the bold vision that created the Centre was that accurate weather predictions could be extended from what was then possible – about two days ahead – to an incredibly ambitious target of ten days ahead. Given the then paucity of high-performance computing power and observations such as from satellites, it was indeed a bold vision. The context for today's NWP is that the scientific understanding of what determines predictive skill has advanced very significantly. Data assimilation, ensembles providing a range of likely scenarios, and the impact of Earth system components on weather are now integral to the way the weather is forecast. Accurate and reliable medium-range forecasts can only occur if the global short-range, such as the 12 hour forecast is even more accurate. This has opened up the potential for extending how far into the future we aspire to predict various attributes of the weather. No longer is ten days seen as a limit for probabilistic weather forecasting and monthly and seasonal ensemble predictions based on the initial-value approach are real opportunities for further scientific development. Whilst this Strategy clearly builds on ECMWF's previous Strategy, today's context means that global NWP is poised to take bold steps forward by addressing these challenges and opportunities.

With further advances in science and the availability of new observations for instance from novel satellite instruments, global NWP is evolving into comprehensive numerical environmental prediction. The diverse uses and value of environmental information are increasing, as is the importance of open data access. Models are becoming more complex, incorporating a wide range of Earth system components. Environmental monitoring and prediction services (such as the Copernicus programme) are providing opportunities for ECMWF to play a wider role by building on its experience in meteorology and in transitioning research into operations. Diverse funding sources now exist for relevant research and operational provision that will enhance the delivery of this Strategy.

High-performance computing (HPC) has been at the core of ECMWF's activities from its beginning. The utilisation of a significant fraction of ECMWF's computing facility by Member States has expanded, now encompassing research and operational forecasting. The growth in computing performance to achieve exascale performance in the 2020s, will come from evolving supercomputer architectures with increased parallelism. Adapting modelling codes to make them as efficient as possible has always been a focus for ECMWF but the future demands on computing and the character of next generation machines mean that this needs to be taken to another level. ECMWF needs to address the environmental impact of all of its activities to minimise their carbon footprint, not least because its computing will continue to consume significant amounts of energy. In addition, the amount of forecast data will continue to increase substantially because of higher resolution, ensembles, tailored outputs etc. Commensurately, data provision will no longer be limited to the storage and delivery of data, but will involve putting compute performance where the data resides. The ubiquity of "big data" and its convergence with HPC create opportunities based on modelling and data analytics. These computing challenges are shared by the meteorological and climate community worldwide and we aim to tackle them via extensive international collaboration.

In summary, the context for this Strategy is one of rapid changes and developments, and we are presenting below two weather prediction case studies that illustrate some challenges that this Strategy will help address.

IMPROVING OUR FORECASTS – CASE STUDY 1

Tropical to extra-tropical cyclone transition – day 6

Bertha was a North Atlantic tropical storm that briefly reached the status of a category 1 hurricane. Moving north-eastwards close to the coast of North America, it underwent extra-tropical transition, and then travelled eastwards across the Atlantic (*Figure 1*). It brought disruptive strong winds and heavy rain to parts of northwest Europe. Forecasts of this system had significant uncertainty, as illustrated by the large spread of ensemble members' tracks in Figure 1. In some members the system died and did not affect Western Europe. In others the resulting cyclone was extreme and its winds would have led to severe damage. The Extreme Forecast Index in *Figure 2* indicated a potential windstorm over northwest Europe more than one week before the event, but the location and high values of probabilities became accurate only a few days ahead of the event.

Forecasts of extra-tropical transition cases are particularly difficult, partly because the representation of the incipient tropical cyclone suffers from resolution limitations and also because the coupling with the ocean plays a key role. Enhancing model resolution and coupling will allow us to improve tropical cyclone representation, which in turn will have benefits for the forecasts of extra-tropical transition. We expect that the spread in ensemble (ENS) forecasts of cyclone intensity and track will reduce so that our forecasts can provide earlier and more accurate warnings of severe weather.

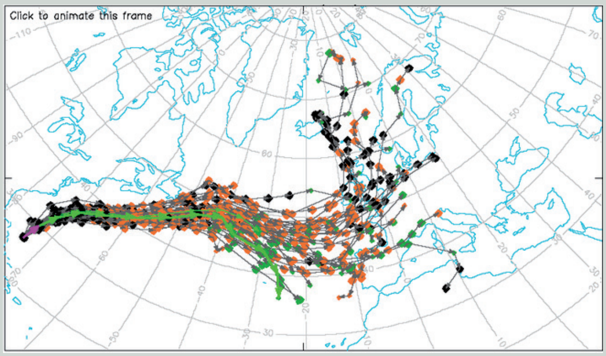


Figure 1. *Tracks of Bertha into the extra-tropics, as forecast by ENS (grey lines), Control (thin green) and HRES (thick green). Western Europe is reached around day 6.*

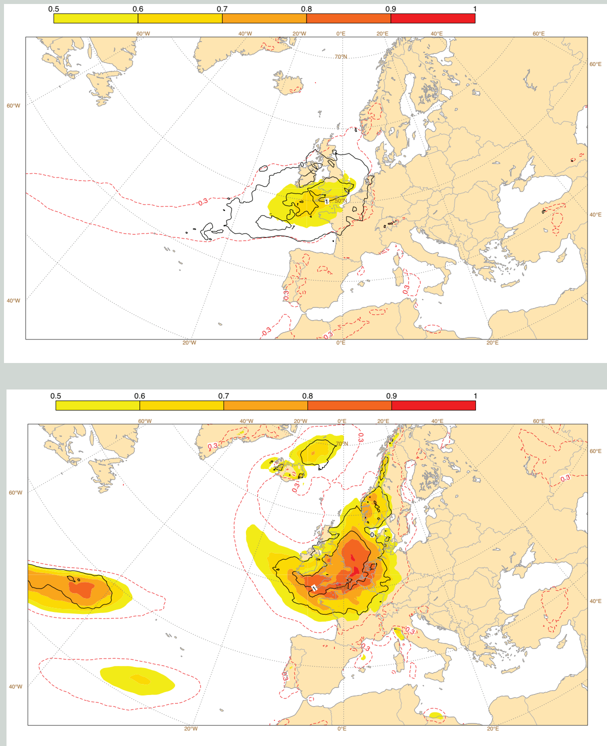


Figure 2. *Extreme Forecast Index of wind speed for the period 10–12 August 2014, at ranges 6 to 9 days (top) and 2 to 5 days (bottom).*

IMPROVING OUR FORECASTS – CASE STUDY 2

European heatwave – week 3

A heatwave affected Europe in summer 2015. It started in Western Europe in June, peaking between 29 June and 7 July 2015, and several temperature records were broken around Europe. Among the records were the all-time high for Germany (5 July), all-time high for Switzerland north of the Alps (7 July), second warmest day on record in Paris (1 July), June record for Madrid (29 June) and July record for the United Kingdom (1 July).

The monthly forecasts for Western Europe issued a few days to a few weeks prior to the event are shown in Figure 3 in terms of weekly-average anomalies with respect to the model climatology. The forecast two and a half weeks prior to the heatwave (initialised on 18 June) predicted a warm anomaly for Europe and the forecast from 22 June strengthened the intensity of the predicted heatwave. However, going back three weeks before the event, the forecast from 15 June failed to show a signal.

Pushing the boundaries of research will help us improve our understanding of the sources of predictability at these timescales and further develop the Integrated Forecasting System (IFS) to be able to extract the predictable signal. Within the next decade, this Strategy aims to bring the performance of the forecast at three weeks and beyond to the level where it currently is for two and a half weeks. This will improve the lead time at which warnings of heatwaves or cold spells can be provided by national meteorological services (NMSs).

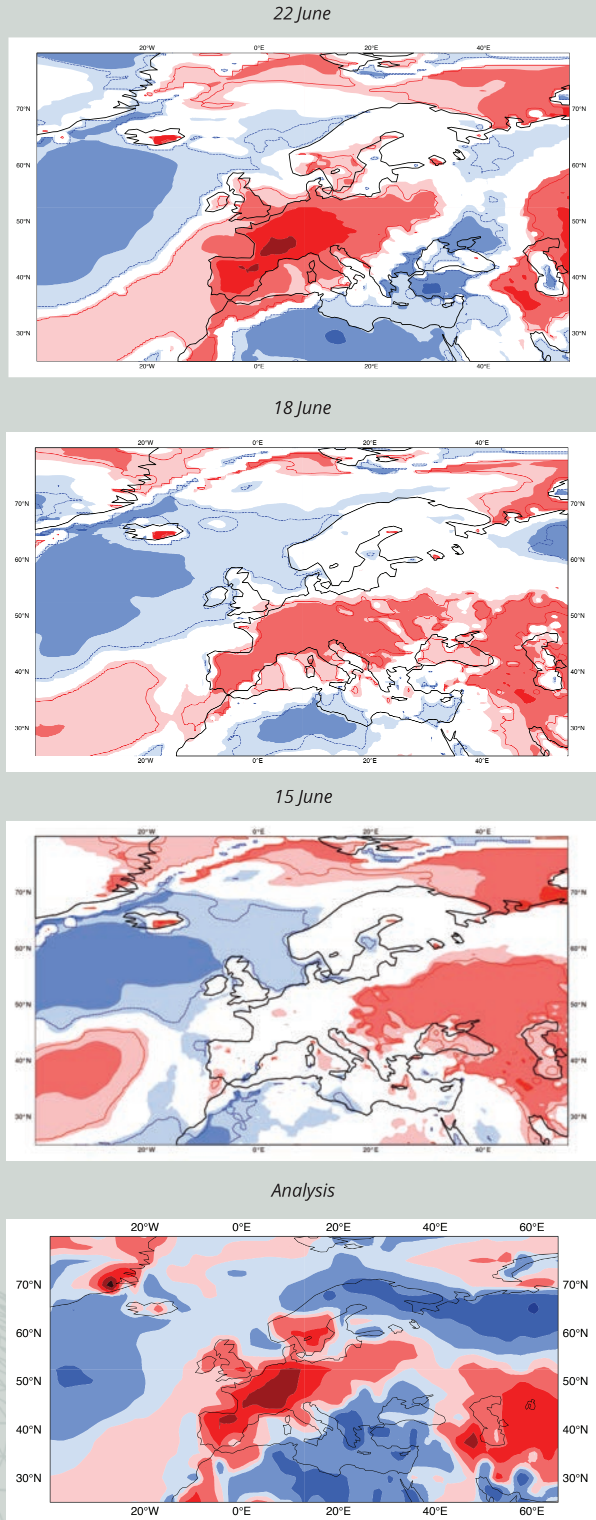


Figure 3. *Forecast for 2-metre temperature: Weekly anomaly for 29 June to 5 July from analysis and forecasts initialised 22 June, 18 June and 15 June.*

ADVANCING WEATHER SCIENCE

One of the two primary goals of ECMWF is to deliver research that will feed into improvements of operational forecast models. To reach the forecast quality goals set out in this Strategy, ECMWF will need research that can significantly enhance the skill of the forecast model and data assimilation system. ECMWF will perform research at the frontiers of knowledge to develop an integrated global model of the Earth system and produce forecasts with increasing fidelity on time ranges up to one year ahead. This will tackle the most difficult problems in global numerical weather prediction and address particular issues such as the currently low level of predictive skill of European weather for a month ahead.

In order to improve forecast skill in the medium range, the two most important scientific goals in the forthcoming decade are:

A **Earth system modelling: incorporating an increased level of complexity of physical and chemical processes and the interaction between atmosphere, ocean, sea-ice and land into the model**

B **Improving forecast skill: through a more accurate estimation of the initial state and through the consistent representation of uncertainty associated with observations and model in both initial state and forecast**

To meet these goals, ECMWF will carry out research on all aspects of global weather prediction relevant to predictions up to one year ahead. These include data assimilation, model development, uncertainty estimation and coupling of Earth system components. Research is required at the frontiers of weather prediction science, investigating new methods that will further enhance forecast skill and fidelity. The research will be conducted through international co-operation, with Member and Co-operating States as well as weather services, universities and computing centres worldwide. In particular, ECMWF will be strongly involved in the World Weather Research Programme focussing on the three main projects on high-impact weather, polar prediction and sub-seasonal to seasonal forecasting. ECMWF will also work in areas of the World Climate Research Programme that are relevant to weather forecasting goals.

In order to assess the impact of ECMWF research, in particular its contribution to the global research community, quantitative goals will be formulated including publications, citations and funding success rates. A special emphasis will be placed on research performance indicators of collaboration.

A Earth system modelling

Earth system model development requires both developments of the individual Earth system components as well as the inclusion of additional components if they contribute to improved weather forecast skill.

Model development

Numerical weather prediction models have evolved from coarse-resolution atmospheric flow models into high-resolution, physically complex Earth system prediction models. Present day forecast models resolve motion scales down to tens of kilometres and include couplings to the land surface and oceans. In order to increase prediction fidelity, new model components and increased spatial resolution are needed.

One limitation in the atmospheric component is the present inability to explicitly resolve convective-scale motions. Moist convection provides much of the vertical heat and moisture transport in the atmosphere, in particular in tropical regions. Improved modelling of the tropics is essential to increase forecast skill in Europe in the medium and extended ranges. High horizontal resolution, coupling to oceans and land surfaces, and a better representation of convective-scale motions are all necessary to improve tropical forecast skill. Heat fluxes between atmosphere and ocean crucially depend on low-level winds and up/down-welling in the oceans. Increased resolution will lead to more accurate modelling of the flux couplings through better wind fields and more accurate ocean dynamics.

For the next decade, research into understanding physical processes will be essential, leading to better parametrizations characterizing sub grid-scale processes, as will be research that investigates ways to represent model uncertainty. A higher degree of scale awareness needs to be built in as processes like convection will be partly resolved, as three-dimensional effects of radiation become important, and as very high-resolution land surface modelling becomes feasible. Developments in cloud and aerosol physics as well as land-surface process modelling will also be essential.

ECMWF has started to design a more flexible dynamical core and enhancements of the current spectral and hydrostatic model are being developed. New numerical methods to handle data efficiently and accurately on unstructured grids will be developed and fully compressible, non-hydrostatic equation systems will be investigated. These will be developed in close collaboration with Member and Co-operating States via the Scalability Programme.

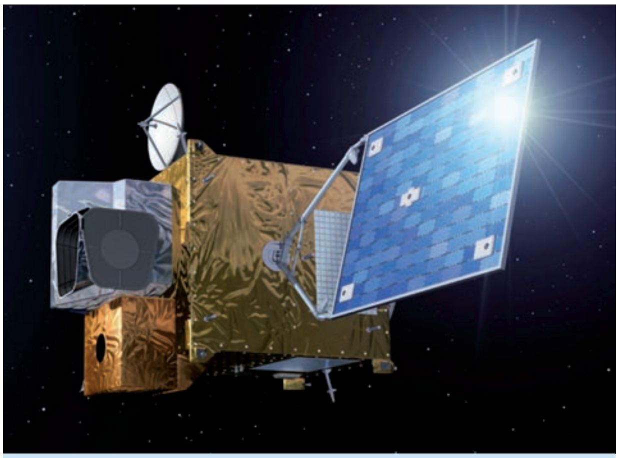
Earth system components

An integrated modelling framework for representing the Earth system including the atmosphere, oceans, land surfaces and the cryosphere is paramount to achieve a seamless analysis and prediction capability. This further implies that the detailed representation of physical and chemical processes and the coupling of atmosphere and surface will be integral parts of the model across all the targeted scales and forecast ranges. Assimilating more Earth system component observations to define initial states is also essential for reducing forecast errors. To cover all aspects of Earth system modelling and assimilation, collaboration with leading research groups around the world is essential.

The framework needs to account for the multi-scale properties of the Earth system in a computationally efficient way. European predictions in the extended range will benefit from an improved representation of land surface couplings and improvements of interactions between the troposphere and stratosphere. Furthermore, aerosol concentrations significantly influence the Earth system energy balance and a better assimilation and modelling of aerosols will contribute to improving global weather predictions.

PARTNERING WITH UNIVERSITIES: OpenIFS

OpenIFS is a recent version of ECMWF's model available for research and training use. It is derived from the IFS, the NWP software system used at ECMWF. The OpenIFS programme helps to strengthen collaboration with universities and other research institutes. One example of research use is experimentation on reduced precision calculations which feeds directly into the Scalability Programme. OpenIFS is also used for academic teaching, providing a numerical model vehicle that can be used to demonstrate how parametrisation changes affect large scale circulation features and weather events. The EC-Earth consortium uses the OpenIFS for the atmospheric component of its Earth system model. All this highlights OpenIFS's growing role in major research projects, involving international collaborations.



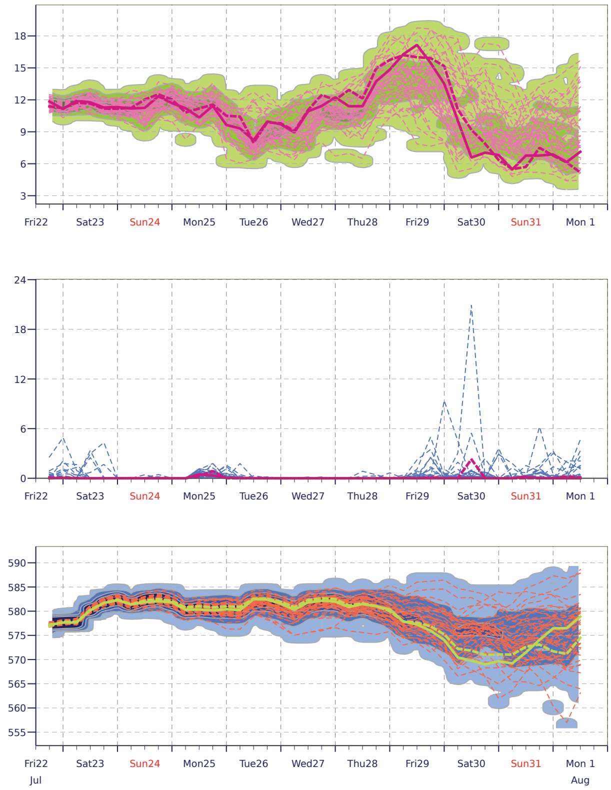
STRATEGIC PARTNERSHIPS
IN EARTH OBSERVATION

Satellite and conventional data are critical to the development and improvement of NWP. ECMWF and EUMETSAT have worked closely together to demonstrate both the value of new satellite observations and how to ensure maximum benefit for Member and Co-operating States from the investment in the satellite programme. This enables ECMWF to make efficient use of current and future observations, in particular from the next generation of EUMETSAT polar and geostationary data which will become available during the Strategy period. ECMWF will also continue to work closely with ESA on evaluating new research and operational satellite missions. Most of the conventional data is supplied by national weather services and includes atmospheric in-situ observations as well as surface observations.

Reanalyses of the Earth system are baseline datasets used for verifying and calibrating forecast model outputs. They are also used to determine climate trends and provide a baseline dataset for atmospheric and ocean research around the world. The strategic objective of developing an Earth system modelling capability for prediction purposes is thus closely linked to the development and production of reanalysis datasets. Reanalysis development also provides a testing ground for new data assimilation methods, both coupled Earth system assimilation development and hybrid variational/ ensemble techniques.

B Improving forecast skill

The range of predictive skill depends on model uncertainty as well as initial state uncertainty. Through data assimilation, observational information is used to reduce initial state uncertainty. All uncertainties need to be quantified in order to predict forecast skill.



Forecast uncertainty can be visualised by forecast plumes, which spread out as the forecast becomes more uncertain. This is shown here in example forecasts of temperature (°C) at 850 hPa (top), total precipitation (mm/6 hours) (middle), and geopotential at 500 hPa (decametres) (bottom), as predicted by HRES (thick dashed line), Control (solid line) and ENS (thin dashed lines).

Data assimilation

Key to accurately predicting the state of the Earth system up to one year ahead is making optimal use of both a model and the global observing system to determine initial conditions. The strategic aim is to further invest in the hybrid data assimilation configuration that combines variational and ensemble techniques such as the Ensemble of Data Assimilations and the Ensemble Kalman Filter. The establishment of a flexible framework that allows an objective evaluation of scientific and computationally efficient variants of the existing elements and also new data assimilation algorithms is considered a crucial starting point. This framework must cater for coupled initialization requirements, in particular for ocean, sea-ice and land, and must remain computationally efficient through enhanced parallelism at the same time. This capability builds the foundation for exploiting the benefits of increased physical complexity, in particular towards increased extended-range predictive skill. The enhanced use of moisture, cloud and precipitation observations is anticipated to constrain the hydrological cycle. Using observations of atmospheric composition, in particular aerosols and greenhouse gases, will directly benefit weather forecasting.

Increased complexity also requires research into the efficient use of observational information from advanced instruments observing the Earth system. Examples of such satellite-based instruments are hyper-spectral sounders as well as active and passive instruments probing clouds, precipitation, aerosols, wind and surface properties for soil, vegetation, snow, sea-ice, lakes and oceans. These activities will continue to be strongly co-ordinated with space agencies and draw on the science community.

Uncertainty estimation

An integral part of the prediction challenge lies in estimating analysis and forecast uncertainty. ECMWF will direct research towards a full integration of ensemble analysis and forecast, seamless in time and resolution, and employing a consistent representation of model uncertainties. With the introduction of more Earth system complexity, increased focus will be placed on the formulation of model errors closer to the origin of physical process uncertainty and their evolution across time and space scales. This will rely on substantial upgrades of data assimilation and modelling diagnostic tools to systematically investigate sources of model error.

The characterization of errors associated with observations and observation operators will be based on diagnostic tools that assess the relative contributions from model and observation uncertainties given the evolving observing system. Further, better knowledge of error correlation in space, time and as a function of the electromagnetic wavelength will lead to state-dependent formulations and adaptive data sampling in these dimensions. The result will be a much enhanced exploitation of the observational information with manageable computational cost.

Predictability

Extended-range predictability will be a strong focus of research at ECMWF. A major frontier is to determine important factors, such as tropical variability, that lead to predictive skill in regions such as Europe on time ranges of a month and a season ahead. Major benefits on these timescales are expected from the inclusion of Earth system components. In general, initial state and model improvements will contribute to extending the time range of useful predictive skill. A better understanding of how predictive skill varies with geographical regions and flow states and is influenced by coupling the atmosphere to components with long-term memory such as the ocean and land surface will also help to identify more predictable situations. For the extended range, producing the right degree of spread of initial state and model uncertainties in the coupled atmosphere-ocean-land system is challenging but advances here are expected to enhance predictive skill. In the coming decade research will focus on the extraction of useful prediction information from Earth system models and in particular on identifying flow situations that are potentially more predictable than others.

DELIVERING GLOBAL PREDICTIONS

One of the two primary goals of ECMWF is to deliver operational weather forecasts to its Member and Co-operating States. ECMWF will deliver an integrated set of operational ensemble-based analyses and predictions that describe the range of possible scenarios and their likelihood of occurrence and that raise the international bar for quality and operational reliability. Skill in medium-range weather predictions in 2016, on average, extends to about one week ahead. By 2025 the goal is to predict high-impact weather up to two weeks ahead. By developing a seamless approach, we also aim to predict large-scale patterns and regime transitions up to four weeks ahead, and global-scale anomalies up to a year ahead.

The two main goals in delivering ECMWF's forecasts are:

A Creating a fully integrated ensemble system

B Evaluating the quality of the forecasts

Meeting these goals will, on the one hand, help ECMWF better address the inherent forecast uncertainty through fully implementing the Ensemble method in all parts of the forecast system. On the other hand, it will help monitoring and improving ECMWF's forecast skill through the development of a set of probabilistic scores.

George Doyle/Stockbyte/Thinkstock; Celtic-MomentsPhotography/iStock/Thinkstock; gemphotography/iStock/Thinkstock.

GENERALIZED DISCRIMINATION SCORE

One possibility is to use the Generalized Discrimination Score for ensemble forecasts, which can be interpreted as an indication of how often the forecasts are correct in discerning different meteorological outcomes. For the 10-day forecast of extreme wind speeds, we would aim for a 70% success rate, compared to 60% achieved currently and a baseline score of 50% for chance. A skill increase of this magnitude would effectively double our skill when compared to a no skill reference (chance). We aim for equivalent progress in terms of extreme precipitation in the medium range. Similarly, we would target a success rate greater than 70% for the prediction of heatwaves and cold spells for week-3, which constitutes a similar improvement.

A The integrated ensemble

To further improve our ability to predict high-impact weather, we aim to run a high-resolution ensemble system up to two weeks ahead. An ambitious target that depends on scientific, computing and scalability advances is for this ensemble to have a horizontal resolution of about 5 km by 2025. ECMWF Member and Co-operating States indicate that high resolution is essential for the model to simulate the weather phenomena that most affect people and assets and which occur at scales of a few kilometres or less. There are also crucial benefits of high resolution in reducing initial condition errors by being able to assimilate more accurately all types of observations, increasing the accuracy of the numerical calculations and in particular, improving the description of surface weather elements. An ensemble approach is also essential due to the inherent forecast uncertainty, and the need to adequately capture the likelihood of extreme weather because of its potentially disastrous consequences. For the longer timescales, the configurations of the model used for the sub-seasonal and seasonal predictions will gradually converge during the Strategy period.

Ensemble forecasts will be delivered from an integrated Earth system model, as consistent as possible between its various components and throughout the time ranges. Indeed, the impact of Earth system components on the weather forecast is now recognized as being very significant. Including atmospheric composition elements such as aerosols in the forecasting system should improve the weather forecasts, as will tighter links with hydrological models.

As ECMWF progresses towards an even more integrated system, predictions will be presented as a grand ensemble, integrating in an optimal way its various components. These components could include ensemble members with a range of resolutions and initialisation times if combining them can be shown to add value. The use of the ensemble system will be supported through enhanced training on the added benefits of ensemble forecasts and the wealth of information they provide.

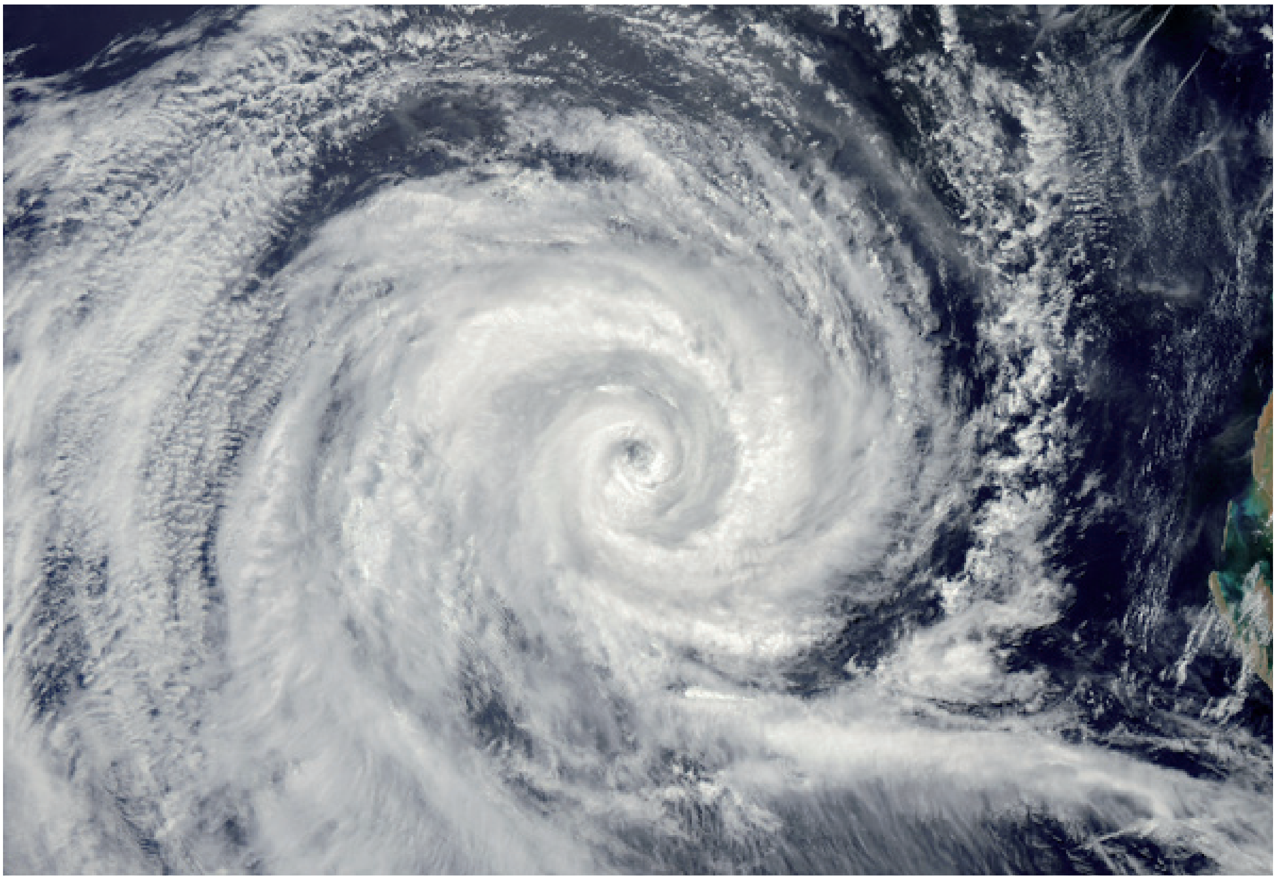
B Evaluating the quality of the forecasts

Forecasting a better future

Forecasts of severe weather and regime transitions are particularly important for ECMWF's Member and Co-operating States and developments will be targeted to address the associated prediction challenges. One strategic goal for the coming decade is to provide economically and societally valuable forecasts of extreme wind speed and precipitation well into the second week of the forecast,

sheilades/iStock/Thinkstock

A severe freezing rain event in Slovenia and Croatia in early February 2014 disrupted transport and caused damage to trees and power lines. While such extreme events are rare, freezing rain and drizzle are not uncommon during the winter months over Europe and North America. A new model cycle launched by ECMWF in May 2015 introduced changes to the cloud and precipitation physics resulting in improved forecasts of freezing rain.



Stocktrek Images/Thinkstock

from the current range of just about one week. Another goal is to extend the range of skilful predictions of extreme temperatures in heatwaves and cold spells to three weeks ahead on average, compared to about two weeks currently. Examples of current state-of-the-art forecasts of these meteorological events are provided on pages 12 and 13. The timeliness and operational reliability of forecasts are essential to ECMWF's members, and will remain a high priority. Timely, improved forecasts will lead to an enhanced protection of life and property through the activities of NMSs in ECMWF's Member and Co-operating States.

Understanding forecast strengths and weaknesses

In order to monitor progress and make relevant choices to maximise the performance of forecasts, an enhanced set of probabilistic scores will be developed and agreed upon, including possible targets. Typically, ensemble forecasts should provide estimates of probabilities of events which satisfy criteria of reliability and sharpness. The forecast is considered reliable if, considering all the situations in the past when a given probability was forecast for a specific event, the event actually occurred with the same probability. The other desirable property of ensemble forecasts is sharpness, by which we mean accuracy characterized by a minimization of the width of the probability distribution. Another area of interest is any day-to-day jumpiness in the forecasts, as this presents a challenge of interpretation for forecasters.

Scores measuring these aspects will be used to assess the forecast performance. Scientific developments including upgrading data assimilation, model physics, optimising the number of members, use of lagged forecasts, and resolution increases will be evaluated for operational implementation on the basis of these relevant scores for the ensemble system. While developing an extensive set of probabilistic scores, building on our experience and latest research in the scientific community, we can attempt to provide some targets directly related to our strategic goals. New skill scores and performance goals will be developed in collaboration with our Member and Co-operating States.

An important factor in forecast improvement is the interaction between research developments, diagnostic studies and the feedback from ECMWF's members. This interaction will be enhanced and the diagnostics component of this loop will be given an even more prominent role.

The importance of accurate reanalyses will further increase, as their use has been shown to be essential for initializing re-forecasts of past events, in the generation of forecast outputs (Extreme Forecast Index, calibrated ensembles), and in the verification of the operational forecasts.

SUSTAINING HIGH-PERFORMANCE COMPUTING

To deliver research and operational forecasting, ECMWF requires high-performance computing resources. When considering computing resources for the forthcoming decade, ECMWF must address two main challenges:

A Scalability: computer codes must be scalable in order to make efficient use of the available computing power

B Providing a high-performance computing facility that allows the benefits of scientific innovation to be realised, in an energy-efficient and environmentally sustainable way

High-performance computing capabilities are instrumental for delivering ECMWF research and forecasts. Tackling the scalability challenge is vital in order to be able to use future computing technologies efficiently and continue to improve the skill of ECMWF's forecasts.

A Scalability

Increasing model complexity and improved resolutions must be scalable in order to use future high-performance computing technology efficiently. Scalability is thus a vital part of ECMWF activities and is conducted within a Scalability Programme. Within the Scalability Programme, ECMWF also has partners from the national meteorological services (NMSs) as well as the computing technology industry.

The evolution towards Earth system modelling at high resolution creates scalability and operability challenges which will be addressed by fundamentally new scientific and computational methods. Scalable code is required in all parts of the forecasting process, from observation inputs through forecast modelling, product generation and forecast delivery to Member State users. The future generation high-resolution ensemble represents a much larger numerical and computational task than today by many orders of magnitude and this will be combined with the expected huge increase in observational data volumes. A change of paradigm is needed regarding an integrated approach to elements such as dynamical core, numerical methods, computer hardware and design of codes. This needs NWP and computational scientific advances to be made in concert at the meeting point of energy-efficient algorithms and technology as well as numerical accuracy and stability. Research projects exploring future heterogeneous computer architectures have been initiated and will be important to prepare for the best possible model given future compute power and data handling constraints.

ECMWF needs to run a system of extremely large dimension at an affordable cost on future computer architectures, to streamline the processing of observations, and to provide the bandwidth for disseminating outputs to the huge range of ECMWF's partners – all within exacting time constraints. An internationally co-ordinated effort is needed to bring together meteorological and Earth system modellers, computer scientists and hardware innovators. This will develop common numerical libraries, work flow configurations, resilience management and efficiency monitoring. This approach also offers an opportunity for co-development with hardware/software providers, for supporting future hardware procurements.

A High-performance computing

Provision of appropriate, effective, resilient and efficient high-performance computing and data archival facilities is key to the successful delivery of ECMWF's research and operational strategy.

Computing technology is both an enabler of science and a driver of innovation in research. The high-performance computing landscape is rapidly evolving and new paradigms such as the use of accelerated systems and the use of high memory bandwidth lightweight cores are continuously emerging. The Centre will therefore maintain close links to the major vendors in order to understand and benefit from their technology roadmaps while also keeping abreast of the development of possible new disruptive technologies. The successful exploitation of new computing architectures is highly dependent on the outputs of the Scalability Programme.

Also tied to the use of future technologies is the question of energy efficiency and power consumption. The Green500 list, which measures the performance of systems in terms of gigaflops per Watt, is dominated by

POOLING EXPERTISE TO IMPROVE SCALABILITY OF DATA ASSIMILATION

Collaboration on object-oriented programming for data assimilation is occurring in the Object-Oriented Prediction System (OOPS project). It aims to improve the scalability and flexibility of data assimilation and to provide a generic framework for data assimilation for all Earth system components (atmosphere, land surface, ocean, waves, sea-ice), as well as simplified models for research. The OOPS project will enable future research in new data assimilation algorithms. A new code structure has already been developed and ECMWF, Météo-France, ALADIN and HIRLAM are working actively together to adapt the IFS code to the new structure. We aim to increase the number of partners in the OOPS project. Within the Scalability Programme ECMWF also has partners from NMSs as well as the computing technology industry.

Jeff Hu/iStock/Thinkstock

MaxMichelMann/iStock/Thinkstock

ENVIRONMENTAL SUSTAINABILITY

Environmental sustainability will remain a key consideration in all areas of our work.

Supercomputers, essential for NWP, consume vast amounts of energy. The Centre will investigate the use of environmentally sustainable renewable energy sources and seek to minimise future operational costs without compromising operational effectiveness.

The development of infrastructure with a low Power Utilisation Efficiency ratio, enabled by systems with higher input and output temperatures, will be a clear driver for the next ten years. In addition, the Centre will develop methods for exploiting new delivery paradigms for computing, such as cloud-based data storage.

We will seek to minimise the environmental impact of our work by embracing the best designs to support sustainable work, travel and operating practices as well as by using sustainable energy supplies.

heterogeneous supercomputers and this trend shows no signs of slowing. Thus the successful exploitation of new technologies is likely to deliver not only effective computing resources but also efficient computation.

As well as considering the efficiency of its infrastructure, ECMWF will continue to focus on the efficiency and effectiveness of its processes. Key to this is the embedding of appropriate industry best practice into its operations. The aim of ECMWF is not to simply adhere to the standards but to critically evaluate those standards, learning from and implementing those sections that add real value in terms of improving the Centre's efficiency, effectiveness and resilience. The Centre will continue to explore computing infrastructure resilience in association with the Member States. This will include robust disaster recovery and business continuity processes.

In summary, the key goals for computing at ECMWF are:

- to deliver appropriate levels of computational resources to satisfy the requirements of the research, operational and Member State communities,
- to deliver efficient, effective and resilient computational resources, applying industry standard best practice where appropriate,
- to be environmentally sustainable.

SUPPORTING ECMWF

To support ECMWF research, forecasting and computing activities both funding and staff resources need to be managed. There are two main future challenges in this area:

A **Funding and people: managing ECMWF's diverse funding streams and attracting and retaining the expertise ECMWF needs to achieve its goals**

B **ECMWF's accommodation: providing a suitable working environment in the context of evolving staff numbers and high-performance computing requirements**

The ECMWF forecast and research goals require an efficient organisational structure set in the context of an intergovernmental institution. Staff is the main asset of ECMWF together with the high-performance computing facilities. Funding and accommodation must be developed in order to provide the necessary support.

A Funding and people

A diversified funding approach

The primary source of funding for ECMWF's mission is the contributions of the Member and Co-operating States. This is complemented by funds from additional sources which the Centre can access by virtue of its leading position in numerical weather prediction and which enable it to progress more rapidly in the delivery of its Strategy. ECMWF will carefully manage these diverse funding streams to ensure that Member and Co-operating States benefit from the leveraging of their contributions with these additional revenues, whilst minimizing risks and ensuring that the Centre retains focus on its mission.

There are significant opportunities for ECMWF to continue to access external research funding in areas which contribute to its overall research strategy. Consortia which include the Centre as a member have been very successful in securing such funding and ECMWF will continue to collaborate with Member and Co-operating States' NMSs and other institutions to co-ordinate and participate in groups to bid for funding. This will continue to be a substantial but not dominating part of ECMWF research resources.

The success of research supported by external funding has itself provided additional funding opportunities for ECMWF to create operational services based on that research, under the Third Party Activity structure. Such funding will contribute to and support the strengthening of ECMWF's infrastructure, allowing the Centre to focus Member and Co-operating States' contributions on the continuing development of its numerical weather prediction research and forecast production to the benefit of its members.

ECMWF aspires to meet the high-performance computing requirements of its Member States for research and forecast production and will consider developing additional Optional Programmes where it may be feasible to respond to requirements that have been identified by many, but not all, Member States.

The Centre will work closely with its Member and Co-operating States to develop effective strategies for funding significant projects (such as ongoing high-performance computing capacity development and its future accommodation needs), which recognise the financial issues some Member and Co-operating States face in the current economic climate.

Attracting the best

ECMWF's people are its key resource. The Centre aims to attract, retain and motivate the staff necessary to implement its Strategy and to retain its leading position in medium-range NWP. ECMWF attracts and will continue to attract the best candidates for positions at the Centre on the basis of its reputation as a world leader in NWP research and forecast production. However, the increasing competition for the best talent and the current economic environment mean that ECMWF must ensure that its recruitment, remuneration, employment conditions and management policies are modern, relevant and support the delivery of ECMWF's Strategy.

The Centre will work closely with its Member and Co-operating States and key organisations such as NMSs and universities to promote a free flow of talent amongst the European meteorological community. Such exchanges allow the Centre to benefit from regularly renewed skills and expertise, whilst providing individuals with opportunities to further develop their skills through a unique platform for international collaboration. To maintain continuity, ECMWF will offer extended contracts to retain certain key skills where needed over a longer term.

In addition, ECMWF will continue its fellowship programme, whereby leading scientists and computing experts are appointed to be ECMWF Fellows. These are titular positions but involve Fellows working with ECMWF on critical issues of interest to both the Centre and to the Fellows, enabling a wider collaboration with the international community.

Within the framework of the Co-ordinated Organisations, the Centre will review its policies to ensure that they offer the best possible environment to attract staff and their families. These policies will be designed to support the careers of staff, both whilst at the Centre and afterwards, and to foster an environment where motivated staff can work together with shared values, common goals and clear objectives which are aligned and connected to the Centre's overall objectives.

B ECMWF's accommodation

The Centre aims to provide suitable accommodation for its staff and its computational infrastructure. Our accommodation needs to cater for ECMWF's anticipated requirements until 2040 and allow for a degree of flexibility to account for the uncertainty in the growth of the organisation, personnel numbers and HPC infrastructure. The building(s) should minimize future running costs and the 'whole life' cost of the infrastructure, and needs to support a significant IT and communications infrastructure with built-in resilience and ensure the safety and security of the occupants. The Centre will seek to minimise its environmental impact by embracing the best designs to support sustainable work, travel and operating practices as well as by using sustainable energy supplies. The Centre benefits from being located close to other scientific organisations to enable the further development of collaboration and co-operation; this reflects and enhances the scientific and technical working culture and ethos of the Centre and helps ECMWF to attract and retain the high-quality international staff that is key to its success.

SERVING MEMBER AND CO-OPERATING STATES

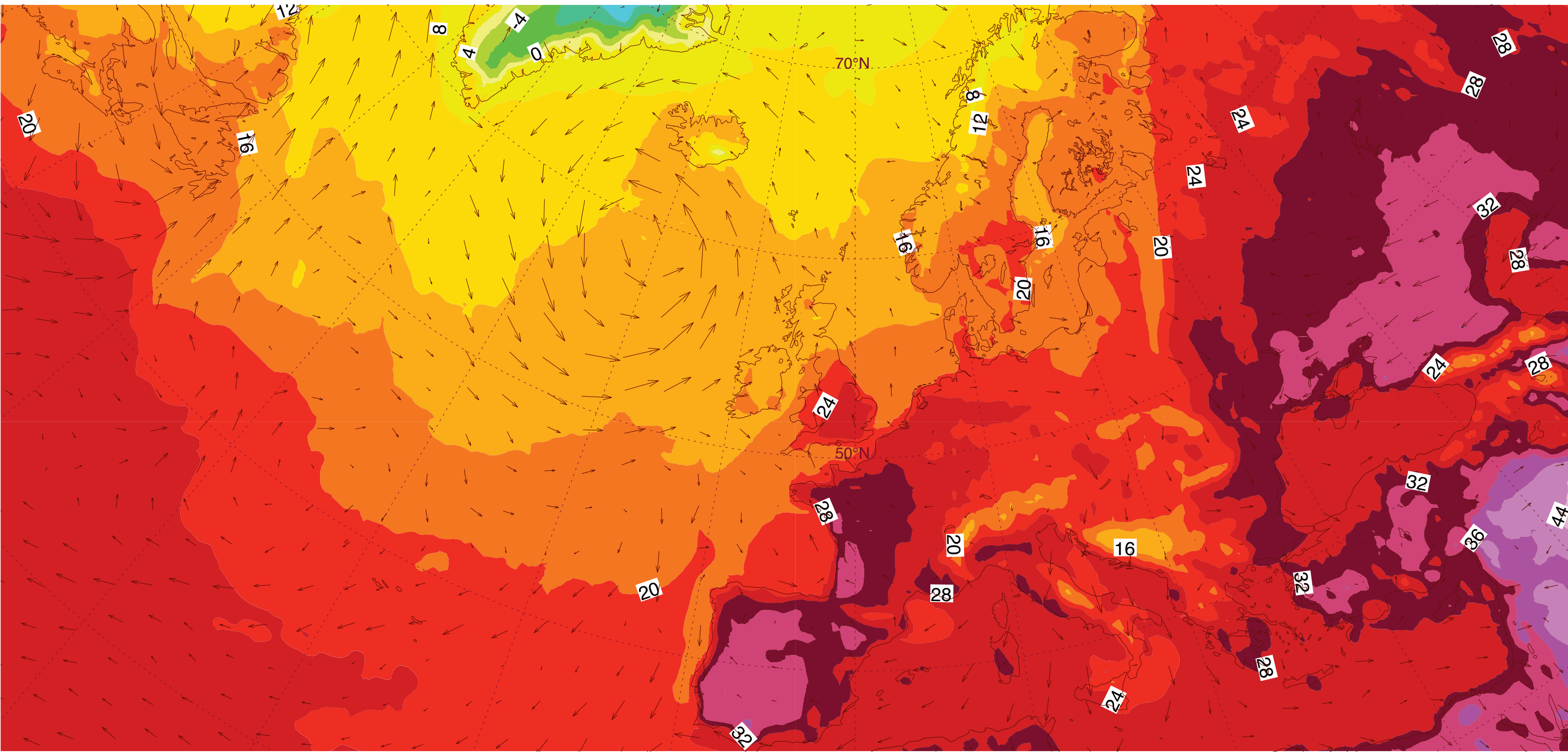
Delivering world-class medium- and extended-range weather predictions for the benefit of its Member and Co-operating States and enabling weather services to tailor these for their end users is at the heart of ECMWF. The Centre serves its community by:

A Making deliverables and expertise available to Member and Co-operating States

B Delivering timely and reliable environmental information

The services provided by ECMWF need to be delivered in an efficient and timely fashion. In addition to medium-range weather predictions ECMWF is also tasked to deliver meteorological databases, computing facilities, training and environmental information capabilities.

One of ECMWF's operational forecast charts showing the 2-metre temperature (shading) and the winds at 30 m above the ground.



A Making deliverables and expertise available to Member and Co-operating States

Forecast outputs

In close collaboration with Member and Co-operating States, ECMWF will create forecast outputs to suit users' requirements. These will take into account the increasing need to obtain condensed information coming from ensemble forecasts, accompanied by appropriate communication and training. The Centre's probabilistic forecast outputs will remain generic, such as median, ensemble mean and spread, percentiles, scenarios representing clusters of large-scale patterns and regime transitions, anomalies, and those indicative of severe weather such as the Extreme Forecast Index. ECMWF will also help the national weather services in its Member and Co-operating States to develop more specific, user-tailored outputs. It is envisaged to offer them the possibility to calculate their specific user-tailored output quantities derived from ensemble forecasts at ECMWF; this will lead to a more efficient use of resources, and reduce the quantity of data needing to be transferred. At the global level, ECMWF will continue to support and benefit from the WMO programmes and working groups active in many areas of mutual interest, and will exploit opportunities to build relationships with other international bodies. ECMWF will also support training and capacity building in WMO member states.

ECMWF will also enhance the forecast capability of Member States by providing initial and boundary conditions for limited-area models as part of an optional programme for those Member States that require it. These models, operated by others, provide finer resolution predictions and use additional fine-scale observations

The monthly time range is becoming increasingly important to ECMWF's users, and although we cannot expect to predict the exact daily weather 30 or 60 days ahead, an ensemble approach can identify flow situations that are more predictable than others. Appropriate post-processing in time and space will also separate the predictable signal from the noise coming from less predictable small-scale and high-frequency components.

Calibration will help to achieve the goal of optimally correcting and combining various outputs. ECMWF will move closer to the ambition of providing seamless forecast outputs across time ranges, and will pursue developments in calibration on the model grid using re-forecasts and other methods.

In Europe, open data have been identified as a cornerstone to better prosperity for citizens, and there are strong initiatives for the public sector to move to an open data policy (PSI and INSPIRE directives), set out in national legislation. ECMWF will work very closely with its Member and Co-operating States to develop policies that take these initiatives into account. We aim to progress in the direction set out by the Oslo Declaration on data policy at a pace in line with our Member and Co-operating States and make sure that such changes are properly communicated to users. There are key issues which will affect data delivery and future funding sources from data sales such as timeliness and performance, spatial and temporal resolution, and significant increases in data volumes. In the future it is very likely that data will become freely downloadable via publicly accessible systems. ECMWF plans also to make available compute facilities and more reliable, supported and customizable delivery services to be funded by users.

PROVIDING COLLABORATIVE DATABASES

The TIGGE archive is operated by ECMWF on behalf of the WMO and brings together past forecasts from a number of centres to enable research in Member States, including in NMSs and academic institutes. Access to TIGGE enables ECMWF and Member and Co-operating States to benchmark their own forecasting systems against independent systems and to carry out comparative case studies to better understand performance issues for specific high-impact events. TIGGE has been used by members to explore the statistical calibration of ensemble forecasts and the potential benefits of multi-model ensemble forecasts.

In EUROSIP, ECMWF works with Météo-France, the Met Office, and NCEP to exchange seasonal forecast data and produce multi-model products in an operational framework. The collected data is also a valuable resource for research and development. There is increasing interest from leading producers in and outside of Europe to join EUROSIP.

Data archives, computing facilities and software

ECMWF will continue to provide meteorological data archiving and computing to its community, utilising the computing and networking infrastructure that has been

REGIONAL MODELLING CO-OPERATION

ECMWF's relationship with Member and Co-operating States can take various shapes and forms, and happen through different platforms. The partnership between ECMWF, Météo-France and the ALADIN and HIRLAM consortia allows participants to use the Centre's global model to develop their regional models. ECMWF and the other groups work together to develop shared codes, which ultimately could help improve the ECMWF model for the benefit of all its Member and Co-operating States. Examples of model code co-operation are the inclusion of a lake model in IFS that was originally developed for the ICON model at DWD, and the ODB software development with the Met Office.

built up over the years as a unique European resource that no one country could create on its own. ECMWF's computing facilities are amongst the largest worldwide for high-performance computing and data archiving dedicated to meteorology. ECMWF's meteorological archive is the largest of its kind in the world and it contains long records of global observations and model-generated data that cannot be found anywhere else. It thus provides a unique resource to its Member and Co-operating States as well as the entire international community, which will be further enhanced through the Copernicus Climate Data Store. ECMWF will also support observational field campaigns for research by providing real-time forecast data relevant for the successful operation of the campaign. With data volumes growing faster than data transfer capabilities, close-to-the-data computing and more generally on-demand computing will form an increasing part of the provision.

A quarter of supercomputing capacity at ECMWF is devoted to the specific needs of the Member States for tasks such as producing regional weather forecasts. The opportunity to expand supercomputer capacity for Member States' usage will be investigated, potentially through the Optional Programme mechanism. In addition, specialist support software and related applications will be developed in collaboration between ECMWF, its participating states and other organisations, thereby enhancing cost-effectiveness. All non-IFS software will be available under an open source licence and external contributions will be encouraged, allowing ECMWF to make the most of community-based developments.

Training

Training is an essential component of ECMWF's mission and thus an important part of this Strategy. Training in numerical weather prediction science, the use of forecasts and computing facilities and technologies increases the knowledge base in the meteorological community in Europe. In addition it has the benefit of broadening the base for recruiting talent at ECMWF from across the Member States. It also contributes strongly to the uptake of the Centre's forecast outputs by a wide variety of ECMWF's partners. The training strategy will factor in other training initiatives in Europe and elsewhere to focus on the unique contribution that ECMWF can make. To complement the face-to-face training that is carried out in dedicated sessions at ECMWF, the Centre will investigate developing a variety of training formats such as e-learning and other forms of distance learning. This broader training experience will provide more options to Member and Co-operating States for training their staff, whilst ensuring cost-effectiveness. In addition, staff from Member and Co-operating States have the opportunity to work at ECMWF via secondment and this enables them to acquire new skills and be trained on the job in new techniques. The OpenIFS initiative is also a mechanism

Participants at the Annual Seminar 2015.

SUPPORTING MEMBER AND CO-OPERATING STATES

ECMWF supports members through regular training courses, as well as operational 24/7 comprehensive user support via a Call desk. The annual meeting on 'Using ECMWF's Forecasts' (UEF) provides a forum for members to give feedback and for the Centre to update them on recent developments in the forecasting system. Specific challenges such as the transition to probabilistic forecasts are being discussed in such forums, where participants can share their own expertise for the benefit of all.

whereby universities can incorporate practical experience with a global NWP model into their training for the next generation of scientists.

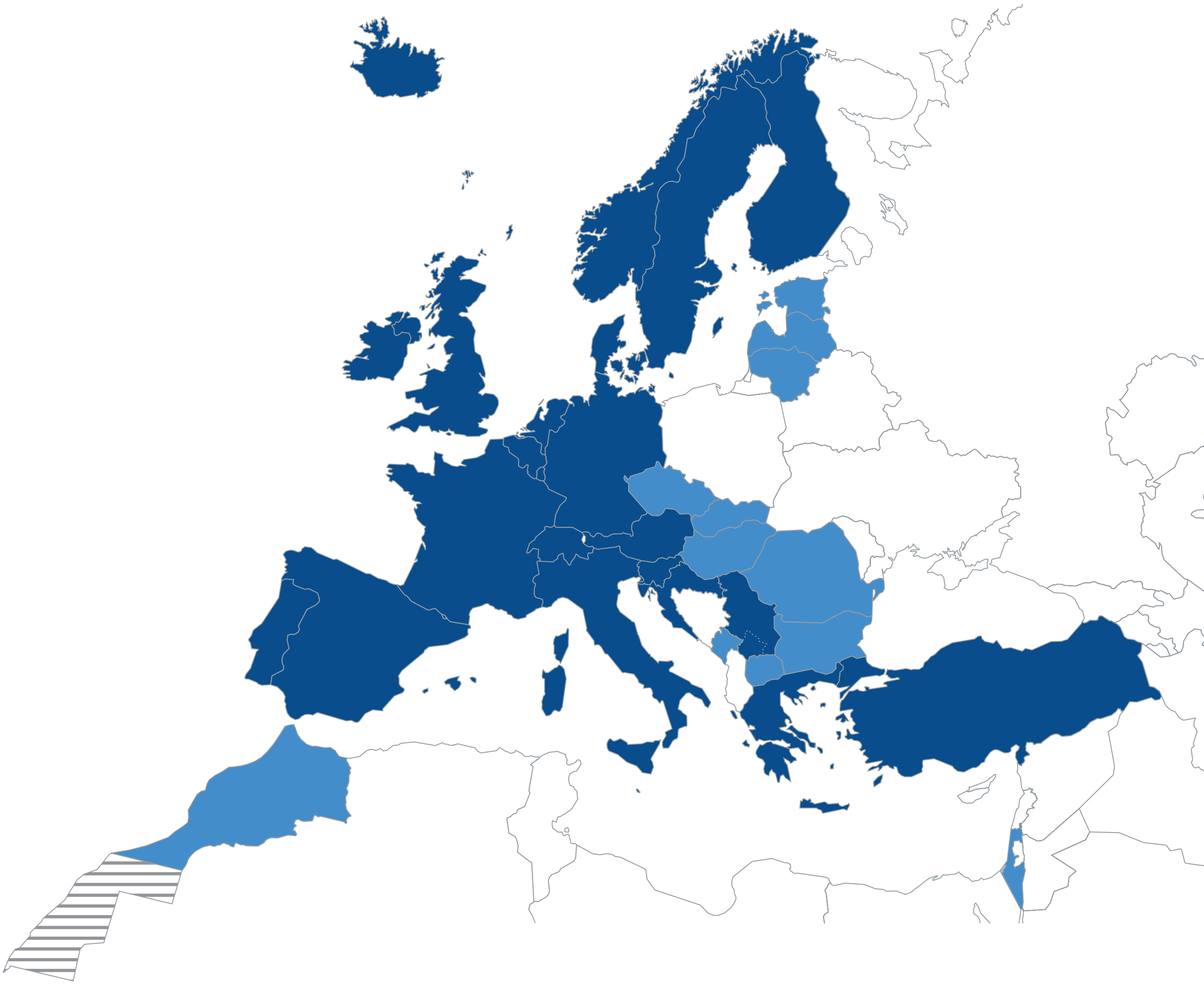
B Environmental information

As global weather models, such as the IFS, develop into more complete Earth system models, there is the opportunity to analyse and predict many other aspects of the natural environment than purely the weather. There is a very significant demand for such environmental information from policy-makers, businesses and citizens across Europe. The Copernicus programme is an example of this and ECMWF is implementing the Climate Change and the Atmosphere Monitoring Services funded by the European Union as a Third Party Activity. In addition, ECMWF operates the computational centre for the European Flood Awareness System, which is part of the Copernicus Emergency Management Service. These operational activities maximise ECMWF's added value for European society. The outputs from these programmes enable authoritative and high quality information, for example, about climate change, air quality, atmospheric pollution, and flooding to be available to European citizens. As this environmental information derives from the same modelling and observational framework as the weather forecast it does not distract ECMWF from its focus on weather and it is fully consistent with the aspirations of the Centre's Convention and its mission.

CONCLUSION

Meeting the challenges that lie ahead over the next decade will require strong partnerships with individuals, institutions and governments. It will be achieved through strengthening existing collaboration with our Member and Co-operating States, maintaining a strong presence at the heart of European and global organisations and networks, and remaining open to new opportunities.

ECMWF is where the shared meteorological goals of its Member and Co-operating States meet. Its role is to go where no one country can go alone; it is to complement and supplement national capabilities, cater for different needs amongst its members and produce the best global numerical weather forecasts the strength of 34 nations with a common goal can achieve.



National Institute of Meteorology and Hydrology **Bulgaria**

Czech Hydrometeorological Institute (CHMI) **Czech Republic**

Estonian Environment Agency **Estonia**

National Hydrometeorological Service Republic of Macedonia **Former Yugoslav Republic of Macedonia**

Hungarian Meteorological Service (OMSZ) **Hungary**

Israel Meteorological Service **Israel**

Latvian Environment, Geology and Meteorology Centre **Latvia**

Lithuanian Hydrometeorological Service **Lithuania**

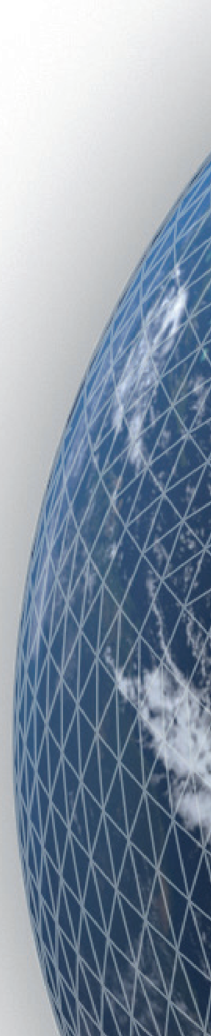
Institute of Hydrometeorology and Seismology of Montenegro (IHMS) **Montenegro**

Météorologie Nationale, Royaume du Maroc **Morocco**

National Meteorological Administration **Romania**

Slovak Hydrometeorological Institute (SHMÚ) **Slovak Republic**

Co-operating States as of January 2016 and their national meteorological and hydrological services



ECMWF, Shinfield Road, Reading RG2 9AX, UK
Tel: +44 118 949 9000
www.ecmwf.int