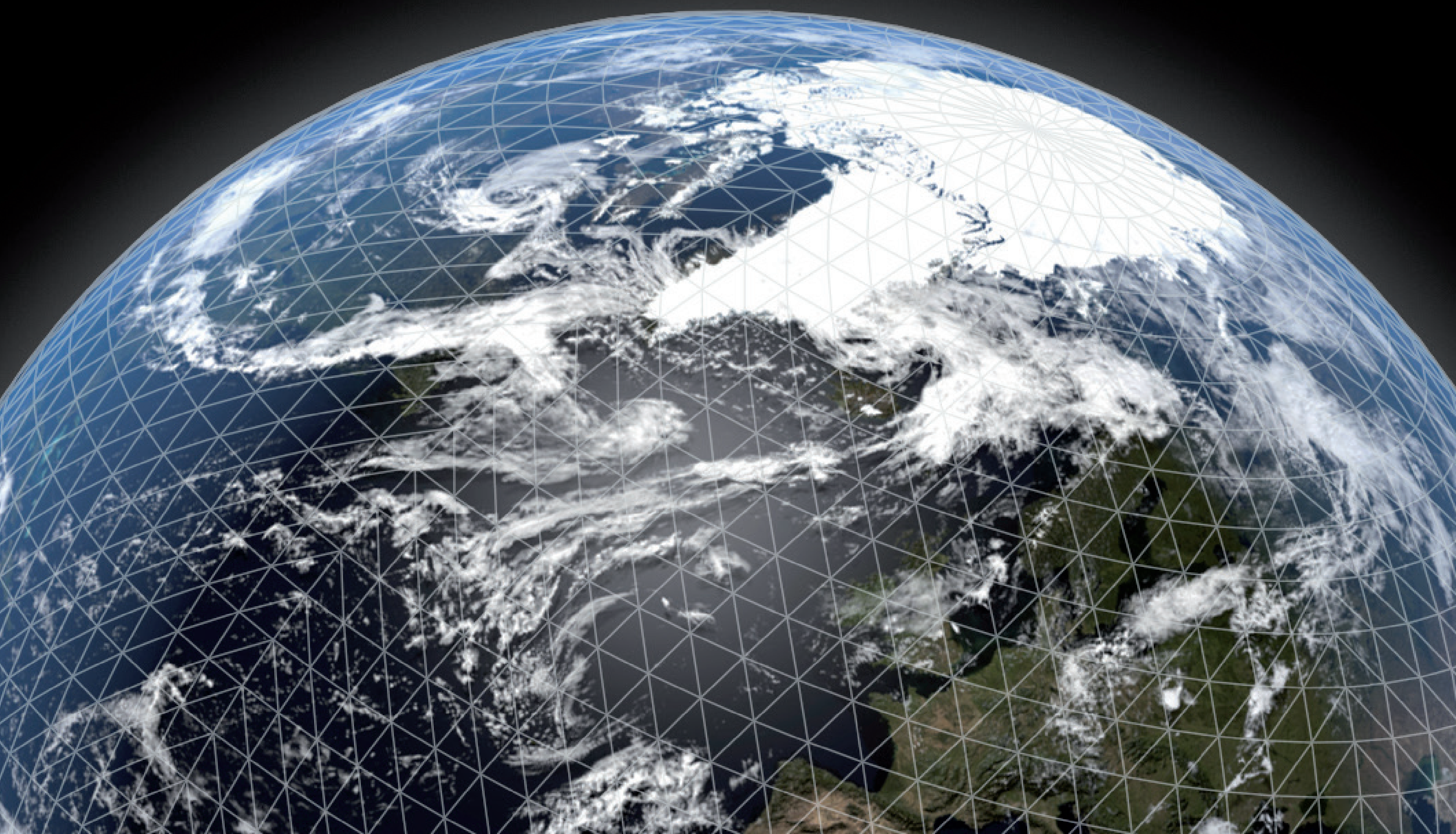
ECMWF

THE STRENGTH OF A COMMON GOAL

A ROADMAP TO 2025



MEMBER STATES AS OF JANUARY 2016

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

CO-OPERATING STATES AS OF JANUARY 2016

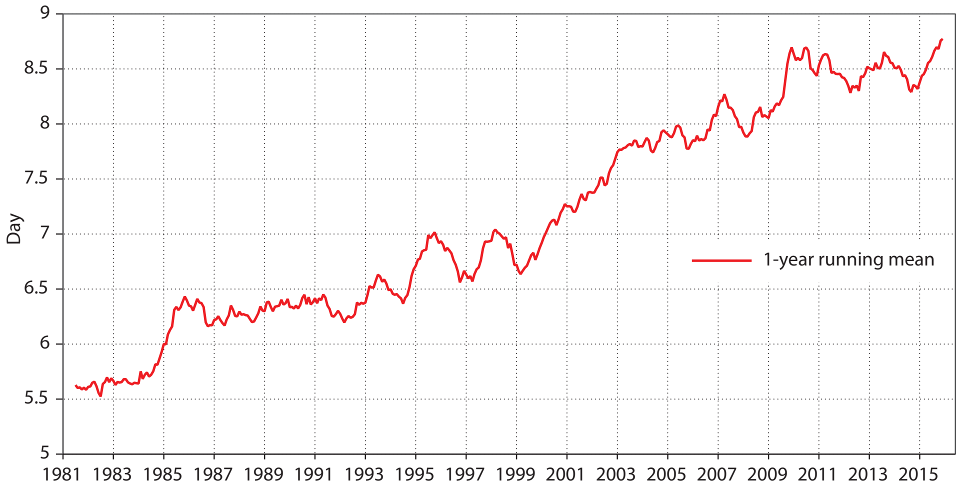
Bulgaria National Institute of Meteorology and Hydrology
Czech Republic Czech Hydrometeorological Institute (CHMI)
Estonia Estonian Environment Agency
Former Yugoslav Republic of Macedonia National Hydrometeorological Service Republic of Macedonia
Hungary Hungarian Meteorological Service (OMSZ)
Israel Israel Meteorological Service
Latvia Latvian Environment, Geology and Meteorology Centre
Lithuania Lithuanian Hydrometeorological Service
Montenegro Institute of Hydrometeorology and Seismology of Montenegro (IHMS)
Morocco Météorologie Nationale, Royaume du Maroc
Romania National Meteorological Administration
Slovak Republic Slovak Hydrometeorological Institute (SHMÚ)

WEATHER MATTERS

ECMWF is an intergovernmental organisation born in 1975 of the will of a few European nations to pool their resources to collectively benefit from improved numerical weather prediction.

ECMWF's role is to develop a capability for medium-range weather forecasting and to provide such weather forecasts to its Member and Co-operating States. To this end, 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. The Centre's principal goal is to improve its global, medium-range weather forecasting products, with particular emphasis on early warnings of severe weather. This in turn gives national meteorological services (NMSs) access to higher resolution and improved data to help them deliver weather forecast services.

Scientific developments at ECMWF are articulated around a ten-year Strategy, developed in close partnership with its Member States, which is revisited and updated every five years. This ensures that it accounts for the latest developments, at scientific, technological and economic levels.



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%.

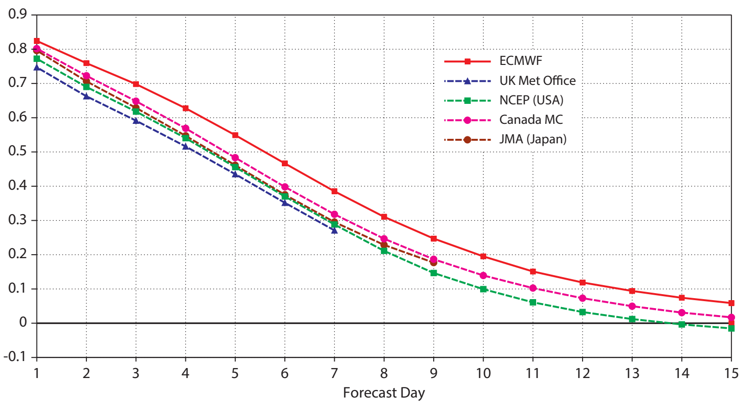
GOALS BY 2025

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 next ten-year Strategy, 'The strength of a common goal', sets the ambitious goal to make skilful predictions of high-impact weather up to two weeks ahead and is giving primacy to an ensemble approach to forecasting. Ensemble forecasts, which provide a range of likely scenarios and give an indication of the confidence forecasters can have in their predictions, became operational at ECMWF nearly 25 years ago. This approach is already enabling ECMWF to capture the likelihood of extreme weather, essential because of its potentially disastrous consequences. To further improve its capability, this Strategy aims to refine the ensemble prediction to a horizontal resolution of 5 km by 2025. To deliver the Strategy's demanding goals, ECMWF is pushing both its modelling and its data assimilation towards an Earth system approach. Whilst Earth system modelling is already in its early stages, its application to data assimilation is very novel and results could be ground-breaking. Since its creation, ECMWF has owed its leading position to the combination of top-level scientists and powerful HPC capacities pulled together by ECMWF's member states in creating a Centre of Excellence. A key priority for ECMWF is on the one hand to remain an attractive proposition for the best scientists in the world, whilst at the same time ensuring it can provide them with the best-fitted computing capability to deliver our core mission.



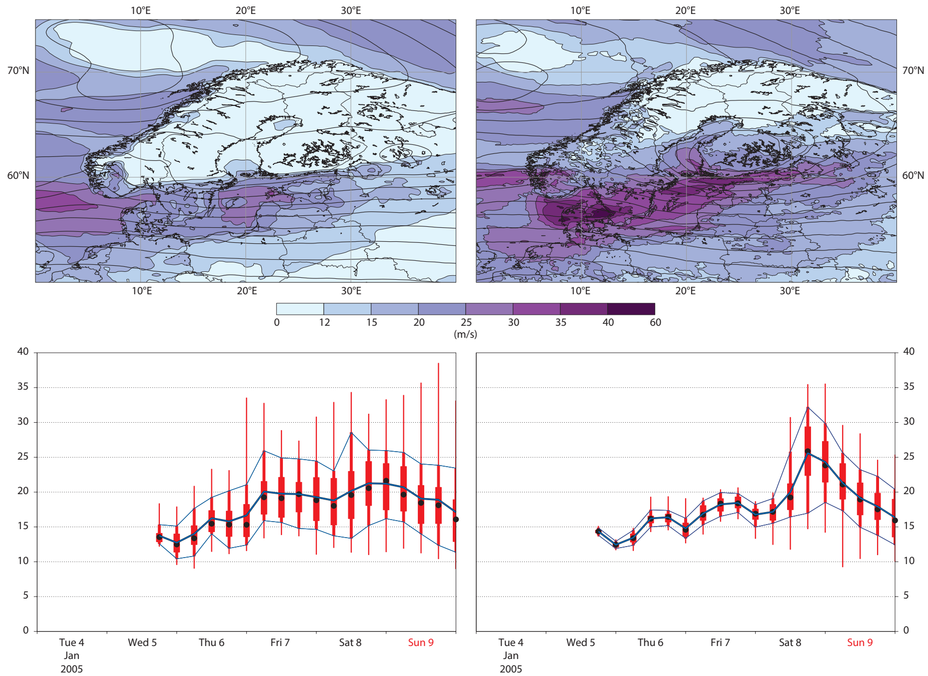
Verification of the Ensemble prediction skill over the past twelve months illustrating ECMWF's performance against other global centres. Higher values mean better skill, with 1 representing perfect forecasts. It is worth noting that not all centres produce their ensemble forecast to two weeks.

WHAT A DIFFERENCE CAN TEN YEARS MAKE?

Weather science has been described as a quiet revolution, as its evolution and progress tend to be incremental. However, ten years of scientific developments do produce advances which can make the difference between life and death if they allow for earlier warnings.

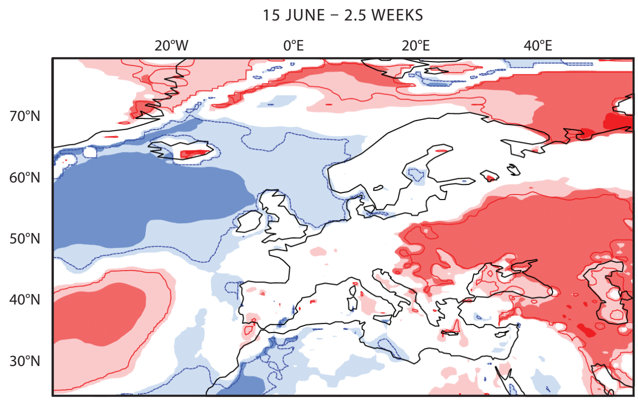
The two examples below illustrate where we aim to be in 2025, at the end of the life of this Strategy.

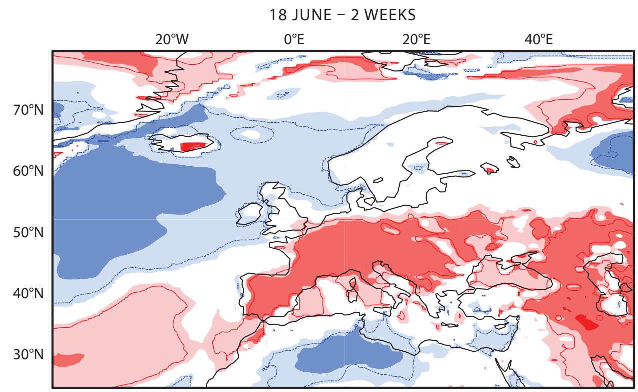
A re-run of forecasts of the Gudrun wind storm, which hit Sweden in January 2005, illustrates how much progress has been made over the past ten years. In today's forecasts, the uncertainty in predicted wind gusts is much smaller than it was ten years ago, as shown by the much narrower range in the box-and-whisker plots. Today's forecasts are also much more accurate: the prediction of wind gusts in excess of 30 m/s in the high-resolution forecast for parts of southern Sweden matches the observed values of gusts between 30 and 35 m/s in the same area much more closely than the values of 15 to 25 m/s predicted at the time. In 2025, we expect reliable forecasts of storms like this one at an average of 10 days ahead of the event, and up to two weeks ahead in some cases.

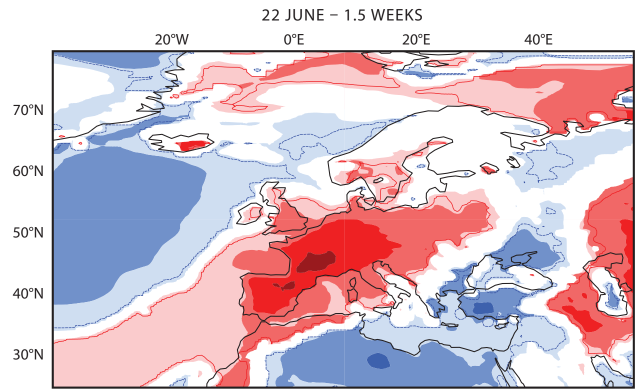


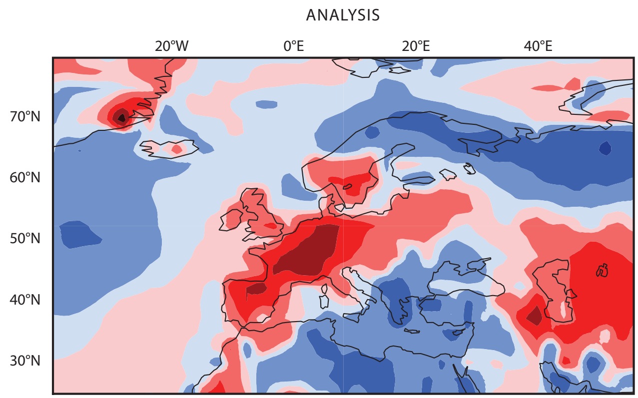
The wind storm Gudrun hit southern Scandinavia on 8 and 9 January 2005. The top left chart shows ECMWF's 3.5-day forecast of surface pressure (contours) and maximum wind gusts (shading) produced at the time. The box-and-whisker plot below shows the corresponding ensemble forecast for an area in the southernmost part of Sweden up to day 4. The right-hand charts show the equivalent forecasts produced using the forecasting system of 2016. The marked improvements seen in today's forecasts can be attributed to better physical parametrization, improved effective resolution, and the way we represent model uncertainty and the flow dependence of model error.

Summer 2015 saw a dangerous heatwave affect Europe, which started at the beginning of July. Though our forecasts make it sporadically visible from two weeks and a half ahead of the event, it became constantly and clearly visible two weeks ahead of the event. This Strategy aims to make such forecasts of high-impact and large-scale pattern events consistently visible at an average of three weeks ahead of the event, and up to four weeks in certain cases, allowing more time for the relevant services and society to prepare.







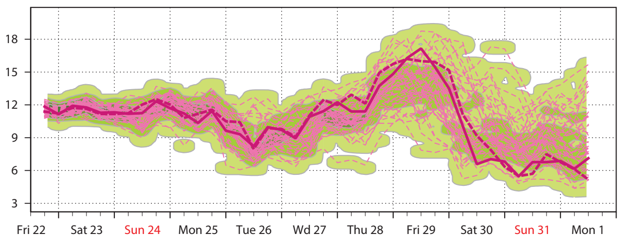


Forecast for 2-metre temperature: Weekly anomaly for 29 June to 5 July 2015 from analysis and forecasts initialised 22 June, 18 June and 15 June.

Pushing the boundaries of research will help us improve our understanding of the sources of predictability at the relevant 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 high-impact weather predictions well into week two, and up to four weeks for larger-scale pattern events. This will improve the lead time at which warnings of heatwaves or cold spells can be provided by national meteorological services (NMSs).

Ensemble prediction: Providing earlier notice of extreme weather events

Improving our ability to predict high-impact weather will rely on running a high-resolution ensemble system up to two weeks ahead. An ambitious target which depends on scientific, computing and scalability advances is for this ensemble to have a horizontal resolution of about 5 km by 2025. That level of resolution is essential for the model to simulate the weather phenomena that most affect people and assets. There are also crucial benefits of high resolution in reducing initial condition errors by being able to assimilate better 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.



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.

An Earth system approach

The key goals of delivering skilful ensemble predictions of high-impact weather up to two weeks ahead and predicting large-scale patterns and regime transitions up to four weeks ahead will require not only an improved model of the atmosphere, but also increased emphasis on additional components of the Earth System including the ocean, waves, sea-ice, land surface, aerosols and all their interactions.

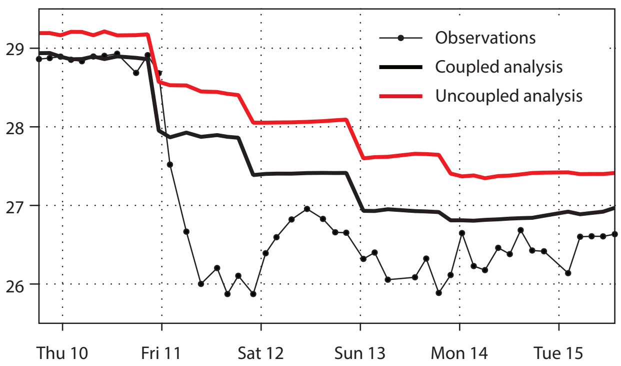
Model development

Present day global forecast models resolve atmospheric scales down to tens of kilometres and include interactions with the land surface and oceans. In order to improve the realism and skill of the predictions, more model components and increased spatial resolution are needed.

For the next decade, research to improve understanding of physical processes in the atmosphere will be essential, leading to better representations of clouds and precipitation, radiation, turbulent mixing and convection. The atmospheric model will be used across an increasing range of spatially resolved scales, from lower resolutions for seasonal prediction to the higher resolution ensemble where deep convection will be increasingly resolved. Research is required to ensure the model's physical processes work effectively and consistently across all these resolutions. Further developments to land surface modelling are essential for all prediction timescales, as well as improving the modelling of the ocean, surface waves, cryosphere and aerosol physics. Research to investigate ways to represent the inherent uncertainty of physical processes in all the components of the Earth system will be vital for an effective forecast ensemble.

Understanding the present: assimilating observations

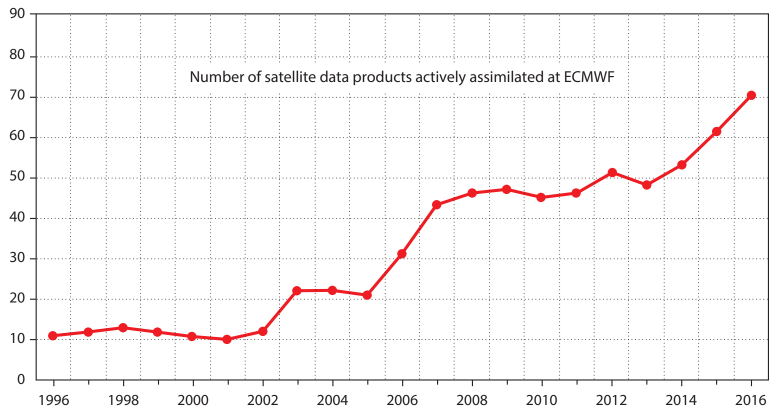
ECMWF's forecast skill is often attributed to its strength and expertise in cutting-edge data assimilation research and technique. Proactive initiatives to find innovative solutions for data assimilation (such as variational techniques, ensemble of data assimilations), as well as very close collaborative frameworks with data providers (EUMETNET for in situ data, EUMETSAT and other space agencies for satellite observations) have played a key role in maintaining ECMWF's lead in this field.



Impact of coupled assimilation during a cyclone. *The dotted line shows the time series of ocean temperature observations at a depth of 40 metres by an Argo float located on the track of the cyclone Phailin. The temperature drop on Friday 11 October 2013 is due to the cold wake induced by the cyclone. The difference between the red and the black thick lines shows the impact of using a coupled assimilation system. The coupled analysis (black line) is closer to the in-situ observations partly through the better use of surface wind satellite measurements.*

As ECMWF's forecasts progress towards coupled modelling, interactions between the different components need to be fully taken into account, not only during the forecast but also for the definition of the initial conditions of the forecasts. ECMWF has started to explore a new coupled assimilation system to initialise the numerical weather forecast in a more comprehensive and balanced manner. Such an approach has the potential to better use satellite measurements and to improve the quality of our forecasts. It will generate a reduction of initialisation shocks in coupled forecasts by fully accounting for interactions between the components. It will also lead to the generation of a consistent Earth-system state for the initialisation of forecasts across all timescales.

Our strategy of higher spatial resolution and increased coupling of different components of the Earth system will require new observations. Though ECMWF uses observations from many types of instruments, ranging from balloons and radars to aircrafts, over 95% of the 40 million observations processed daily are provided by satellites. ECMWF works very closely with space agencies around the world, and specifically with its sister organisation EUMETSAT, to ensure that instruments meet the needs of meteorology. The next ten years will see the first hyperspectral instruments in geostationary orbit, as well as EUMETSAT's 2nd Generation Polar System in Low Earth Orbit, which will contain new and improved instruments, as well as strengthening the core microwave sounding capability. We will also work closely on the next-generation US system, JPSS, and the evolving Chinese programme, Feng Yun. In addition there are exciting technology and science demonstration missions such as ESA's ADM-Aeolus and EarthCARE where ECMWF is, and will seek to remain, at the forefront of research into the assimilation of new observations.



This graph shows the number of satellite data products actively assimilated at ECMWF. The Centre processes an average of 40 million observations every day, from over 70 instruments. Collaboration with sister organisation EUMETSAT, and also ESA, CMA, JMA, NASA, NOAA among others ensures that ECMWF has access to the observations meteorology requires. ECMWF's use of satellite data is only going to grow with the exciting advances in space technology and launches of new instruments planned by space agencies.

A scalable approach to supercomputing

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. Thinking of computing capability independently from a scalable approach is not an option. To deliver these ambitious goals, whilst remaining both economically and environmentally sustainable, ECMWF needs to ensure it will have access to the best-fitted computing technology, whilst simultaneously further developing its scalable approach to code development.

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

A scalable code is required in all parts of the forecasting process, from observation inputs through forecast modelling, and from generation to delivery of the forecasts to Member State users. The future generation of high-resolution ensemble prediction 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. Whilst volumes increase, production time will still have to remain within one hour in order to meet Member States' stringent deadlines. At the same time, the high-performance computing landscape is rapidly evolving and new patterns, such as the use of accelerated systems and the use of high memory bandwidth lightweight cores, are continuously emerging. A change of paradigm is needed to implement an integrated approach to elements such as numerical methods, computer hardware and design of codes.

The successful implementation of this Strategy requires numerical weather prediction and computational science to advance in concert towards energy-efficient algorithms and technology, as well as numerical accuracy and stability. It also revolves around the Centre maintaining and building upon its close links to the major vendors in order to benefit from their technology roadmaps whilst keeping abreast of the development of possible new disruptive technologies.

Research projects exploring future heterogeneous computer architectures have already been initiated and will be important over the life of this Strategy to prepare for the best possible model, taking into account and meeting future compute power and data handling constraints.

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

Over the past forty years, ECMWF has benefitted from the support of its growing number of Member and Co-operating States: support in funding as well as in scientific co-operation and expertise sharing. ECMWF has also expanded its collaborative approach through different types of co-operation with meteorological services, research centres, universities and space agencies across China, the USA, Brazil, Japan, and of course through the World Meteorological Organization (WMO). Though independent from it, ECMWF also has a strong partnership with the EU. Research grants from the EU have allowed the Centre to advance its expertise in the areas of scalability and seasonal forecasting among others. More recently ECMWF has become the operator of two services of the EU-flagship Copernicus Programme, for climate change and atmospheric monitoring.

This Strategy is the fruit of this wide-ranging collaboration, and its success relies on the collaborative spirit that has been the essence of ECMWF and its community.