ECMWF

European Centre for Medium-Range Weather Forecasts

Annual Report 2017

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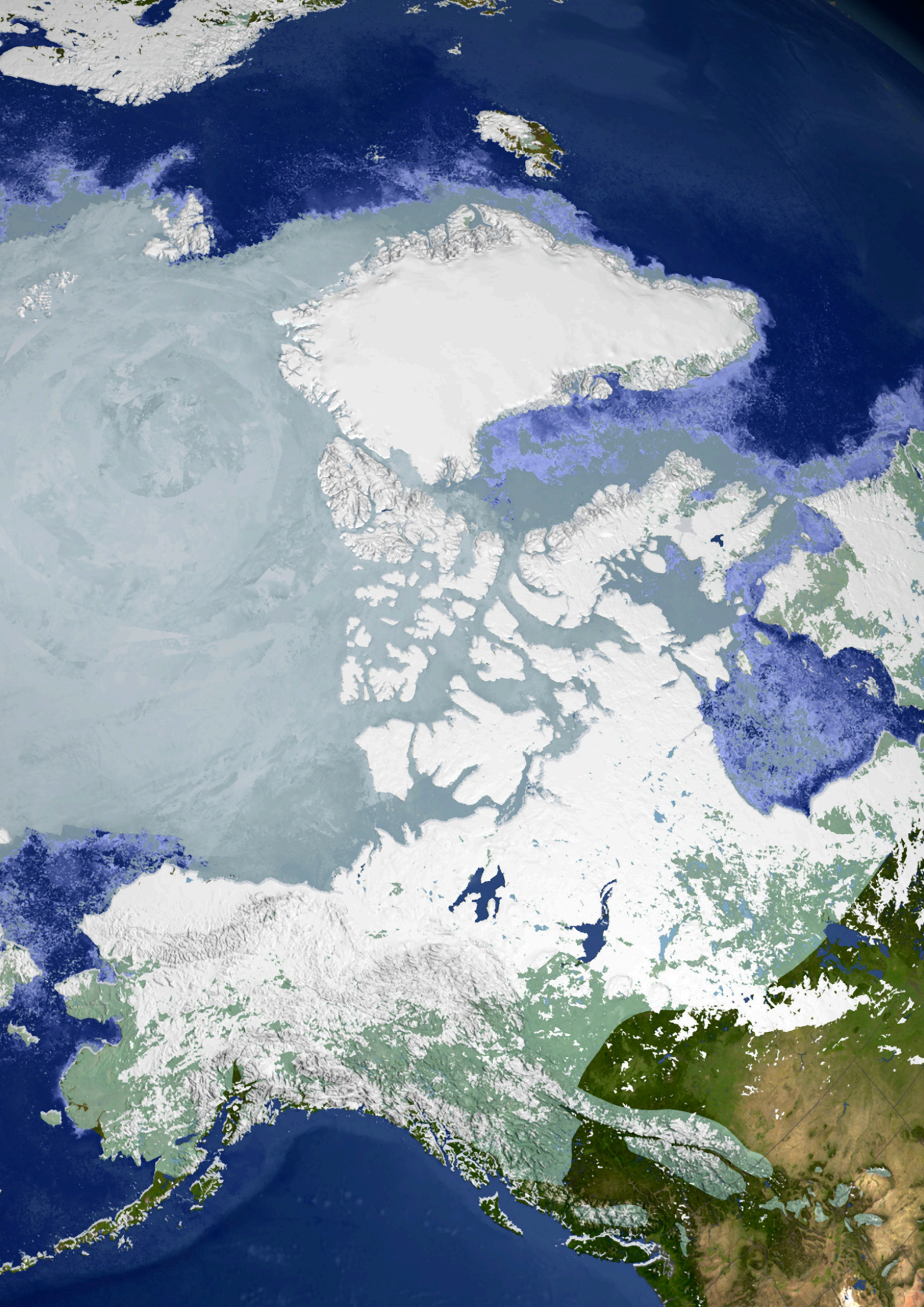


Member States as of January 2018

Austria
Belgium
Croatia
Denmark
Finland
France
Germany
Greece
Iceland
Ireland
Italy
Luxembourg
The Netherlands
Norway
Portugal
Serbia
Slovenia
Spain
Sweden
Switzerland
Turkey
United Kingdom

A year among years

Florence Rabier
Director-General

There is a lot to say about 2017, and the following pages allow us to remember or discover some of the key moments. Possibly the most striking aspect that comes to mind is the way our past, present and future collided in that specific year.

2017 was a firework of anniversaries. It marked 20 years of 4D-Var at ECMWF, and of seasonal forecasts, and 25 years of ensemble prediction and wave forecasting. It was also the year when ECMWF's Council approved the development of our future data centre in Bologna, Italy, and voted a budget allowing a substantial increase in our computing capability. The end of the year saw the Government of the UK, our host nation, formally offering to relocate ECMWF's headquarters to accommodate our requirements.

A common denominator between all those events is that they illustrate the relationship based on trust which connects ECMWF and its Member States. The science behind ensemble prediction or 4D-Var was not born in one day. It took years and years before it even looked like something which could be adequately demonstrated. Developing a state-of-the-art data centre is also a substantial investment in the future. These are strong statements of support from the Member States.

Trust is earned, and 2017 has allowed us to pay our dues and serve our Member States and other users with some noticeable progress towards our Strategy to 2025. Some good examples include the work undertaken to assess the best ensemble configurations to make a 5 km ensemble affordable; the more efficient radiation scheme, completely recoded to be more flexible and delivering efficiency gains up to 30-35%; the release of the new seasonal system, SEAS5, notably improving El Niño prediction.

Our partnership with the European Union is also thriving and delivering results that cut across the whole of ECMWF. The new climatology derived from aerosol data developed by the EU-funded Copernicus Atmosphere Monitoring Service that we operate on behalf of the EU is contributing to improving our forecasts. The latest version of our reanalysis, ERA5, produced by our Copernicus Climate Change Service now provides a useful benchmark and reference for identifying interannual

Probabilistic skill

ECMWF's duty to Member States is to continue improving medium-range forecast skill. Results for the northern hemisphere extratropics show that the skill of the ensemble forecast in predicting 24-hour precipitation totals continues to increase. The computation of skill is based on the continuous ranked probability skill score (CRPSS). The chart shows 12-month running average values of the forecast range at which the CRPSS drops below 0.1.

variations in predictability; last but not least, this strong partnership with the EU is reinforced by the work they have selected us to deliver on fire prediction and human carbon emissions.

Our work with the WMO continued to flourish in 2017, with Nguyen Thanh Tung from Vietnam finishing his fellowship in September after 12 months of mutually beneficial exchanges. This year the WMO designated ECMWF as a World Meteorological Centre and endorsed us as the Lead Centre for Wave Forecast Verification.

ECMWF is above all a scientific organisation, so the arrival of Dr Andy Brown as Director of Research is also a milestone of 2017. Andy joined us one year into the implementation of the Strategy to 2025, with sizeable challenges to address … and an impressive scientific team to support him.

Science in numerical weather prediction could not function any more without the support of computing sciences and technology, so Council's approval of our next HPC budget at its December session was a great outcome. Six months after approving the building of our new state-of-the-art data centre in Bologna, Council confirmed its confidence in our teams by endorsing our request for a substantial increase in computing capability. As we continue to push our science towards the goals of our Strategy to 2025, there could not have been a better way to end 2017.

2017 At a glance

January

CAMS model upgrade

Changes to the aerosol model of the Copernicus Atmosphere Monitoring Service (CAMS) global forecasting system operated by ECMWF on behalf of the EU resulted in more accurate forecasts. The upgrade introduced two new satellite datasets: aerosol observations from the Polar Multi-Sensor Aerosol Product (PMAp) provided by EUMETSAT and ozone observations from the Ozone Mapping Profiler Suite (OMPS) provided by NOAA through EUMETSAT's third-party data programme. These will help to define the initial state on which forecasts are based.

February

Fire danger reanalysis goes online

Copernicus fire danger reanalysis products from the Global ECMWF Fire Forecast (GEFF) system became available online, providing historical records of global fire danger conditions from 1980 to today. The products were developed at ECMWF over the last three years as part of the EU-funded Copernicus Emergency Management Service. They complement other Copernicus products related to fire, such as the biomass-burning emissions made available by CAMS.

Windstorm Doris

On 23 February, Storm Doris hit Ireland and Great Britain, causing disruptions and at least one fatality. The risk of extreme gusts was predicted well 6–7 days in advance, but there were still uncertainties in the details in the forecast one day before.

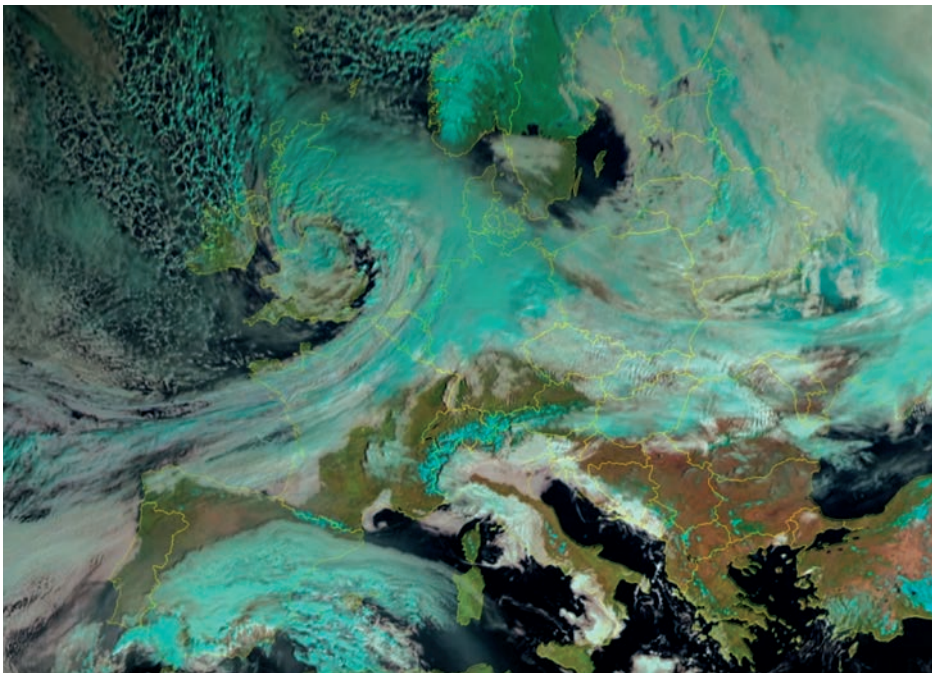
March

Open data events

ECMWF marked International Open Data Day with a week of events that included an open data hackathon and several workshops. The events aimed to raise awareness of freely available data from ECMWF and the EU Copernicus programme and of the socio-economic impacts of numerical weather prediction (NWP) data.

Earlier dissemination of ensemble forecasts

On 7 March, ECMWF started disseminating medium-range probabilistic forecasts to its users 40 minutes earlier than before. The move was made possible by an upgrade of ECMWF's supercomputers in 2016. Forecasts are now available as early as 0800 UTC. This can be beneficial to users who need to make weather-based decisions early in the day.



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Predicting weather impacts

Scientists, developers and emergency managers from across Europe came together at ECMWF to drive forward the three-year ANYWHERE project, funded under the EU Horizon 2020 Programme. The project aims to develop forecasts of weather impacts in Europe, such as damage from windstorms, floods and heatwaves. ECMWF's key role in the project is to provide weather forecasts in support of other partners' modelling applications.

April

Support for Peru flood response

ECMWF forecast data were rapidly made available to Peru's national meteorological and hydrological service (SENAMHI) as heavy rainfall and flooding swept across the country during the early months of 2017. Forecasts, including our new point-rainfall product, helped SENAMHI forecasters to issue warnings of heavy rainfall and highlight events that might hinder rescue operations.

May

ECMWF launches eLearning

To meet the training needs of its Member and Co-operating States, ECMWF launched the first of its publicly available eLearning modules, which give learners flexibility in terms of when, where and how they want to learn. The new modules are enabling the Centre to shorten face-to-face training events and reduce costs for Member States.

Ten years of atmospheric composition forecasts

ECMWF's first forecast of atmospheric composition in May 2007 paved the way for the Copernicus Atmosphere Monitoring Service (CAMS), which held its second General Assembly in Warsaw, Poland, in May this year.

Support for WMO Year of Polar Prediction

As the World Meteorological Organization (WMO) launched its Year of Polar Prediction (YOPP), ECMWF began work to generate an extended two-year dataset to support the programme.

2017 At a glance

June

User meeting focuses on storms

More than 100 forecasters and scientists attended the Using ECMWF's Forecasts (UEF) meeting, where the theme this year was 'Storms'. It focused on areas such as the processing of model outputs to support the forecasting of severe storms and associated weather phenomena; diagnostics involving tools or studies that highlight strengths and weaknesses of ECMWF's Integrated Forecasting System (IFS) in predicting storms; and the impact of storms on sectoral applications.

Symposium on dynamical meteorology and NWP

Leading WMO officials and experts in NWP came together at ECMWF for a symposium to mark the departure of Erland Källén from the Centre after eight years as Director of Research. Delegates heard about new results in dynamic meteorology, operational NWP and climate science as well as about the Centre's past, present and future.

OpenIFS user workshop

The fourth OpenIFS user workshop, held in Trieste, Italy, was devoted to 'Atmospheric Variability: seasonal predictability and teleconnections'. It attracted scientists from institutes in Europe and further afield. In hands-on sessions, they investigated what the weather would have been had the strong El Niño of 2015/16 been different.

Bologna to host data centre

At the 90th session of the ECMWF Council, Member States approved the proposal by the Italian Government and the Emilia-Romagna Region to host ECMWF's new data centre in Bologna, Italy, by 2019.

July

Model upgrade improves forecast quality

ECMWF's Integrated Forecasting System (IFS) was upgraded to IFS Cycle 43r3. The changes included improvements in the modelling of convection, a new radiation scheme and aerosol climatology, and better use of dropsonde and other observations. The upgrade brought a range of improvements in forecast skill and in tropical cyclone forecasts in particular.

New Research Director takes up post

Dr Andrew Brown, previously Director of Science at the UK Met Office, became ECMWF's Director of Research.

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ECMWF Fellowships renewed

The three original ECMWF Fellows, Tim Palmer, Tilmann Gneiting and Rupert Klein, began second terms of three years.

Powerful climate monitoring dataset from Copernicus

The Copernicus Climate Change Service (C3S), operated by ECMWF on behalf of the EU, released the first part of a powerful global climate monitoring dataset, known as the ERA5 climate reanalysis. This initial release of ERA5, covering 2010 to 2016, made a vast amount of climate data freely and openly available. Data include air temperature, pressure and wind at different altitudes, and surface parameters such as rainfall and sea ice.

August

Co-operation agreement with INPE, Brazil

ECMWF and Brazil's National Institute for Space Research (INPE) signed a formal co-operation agreement on 1 August. This came after many years of working together, especially in the development of the Metview meteorological workstation application.

ECMWF designated World Meteorological Centre

ECMWF was designated as a World Meteorological Centre (WMC) by the WMO. WMCs have to meet a range of standards on data, products, documentation and training. They provide WMO Members with a range of forecast products.

Heatwave in Europe

The unusually high temperatures in early August, across much of central and southern Europe, were well forecast by ECMWF. Potential heatwave conditions were evident around four weeks in advance and short-range forecasts correctly predicted the severity of the event.

September

Royal Society Research Fellowship

ECMWF scientist Peter Düben was awarded a prestigious Royal Society University Research Fellowship to continue his research into uncertainty and the computational efficiency of NWP. The five-year fellowship is intended for outstanding early-career scientists who have the potential to become leaders in their field.

Annual Seminar on ensemble prediction

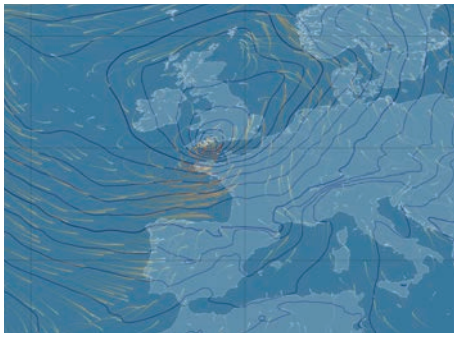
More than 100 people from across the world joined ECMWF scientists and 28 speakers at ECMWF's Annual Seminar on 'Ensemble prediction: past, present and future' to discuss how to further improve the accuracy and reliability of ensemble-based forecasts.

2017 At a glance

October

ERA5 reanalysis simulates Great Storm of 1987

The power of the new ERA5 climate reanalysis was demonstrated with a detailed, hourly simulation of the evolution of this notoriously difficult-to-capture storm over Western Europe, including the sting jet that made it so destructive.



CO_2 Human Emissions (CHE) project

October saw the start of a major project led by ECMWF to explore the development of a European system to monitor human-related carbon dioxide (CO_2) emissions across the world. Such capacity is vital to support Europe's leading role in worldwide action to address climate change. The project brings together a consortium of 22 European partners and will last for over three years.

Test phase for new interpolation package

ECMWF's new interpolation package, MIR, was made available to ECMWF users for testing. MIR is a library of routines for the interpolation and regridding of meteorological fields. It illustrates how NWP research and software/hardware development must go hand in hand. Its flexible design will allow it to be adapted to future developments.

November

Anniversaries and celebrations

2017 provided ample opportunity to reflect on scientific achievements and progress. The year marked 25 years of ECMWF's production of ensemble forecasts, 25 years of wave forecasting at ECMWF, 20 years since ECMWF implemented a pioneering four-dimensional variational data assimilation technique (4D-Var), and 20 years of producing seasonal forecasts.

Towards global modelling at resolutions under 10 km

The ECMWF Strategy aims for global ensemble forecasts at a resolution of 5 km by 2025 and this requires new ways of representing small-scale processes, such as convection, in forecasting models. A workshop brought together 50 scientists to foster international collaboration and discuss how best to make progress on the modelling of physical processes in the grey zone of horizontal resolutions ranging from 1 to 10 km grid-spacing.

New EFAS and GloFAS flood forecasting products

New products became operational in the European Flood Awareness System (EFAS, part of the Copernicus Emergency Management Service): now-casting flash flood forecasting based on radar images, and a Rapid Risk Assessment tool. The Global Flood Awareness System (GloFAS) also launched new seasonal forecast products. Developed jointly with the University of Reading, GloFAS seasonal provides global hydrological forecasts out to four months.

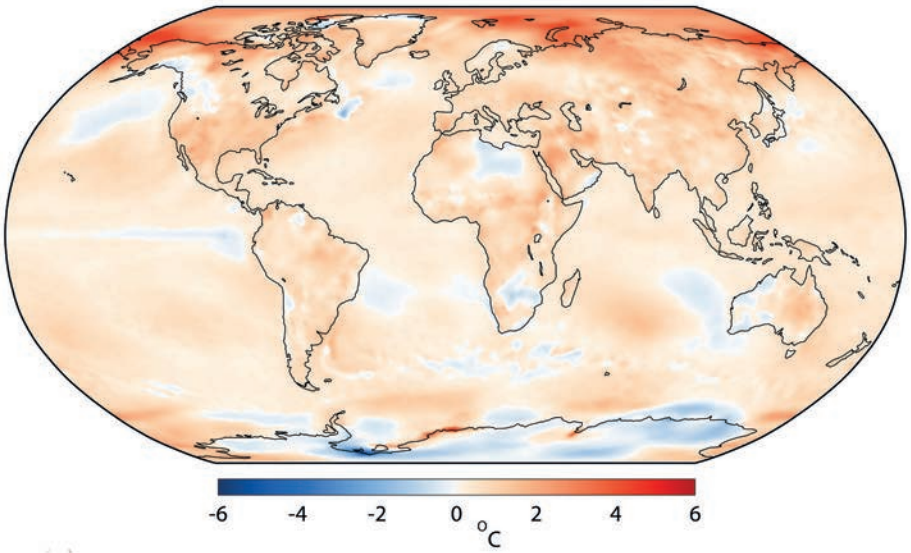
SEAS5 brings better El Niño forecasts

A new seasonal prediction system (SEAS5), which gives an indication of average, large-scale weather conditions out to 13 months ahead, was launched by ECMWF. The new system includes an upgraded ocean model and a model which allows sea-ice cover to respond to changes in the atmosphere and ocean. SEAS5 brings better forecast skill for periodic warming/cooling events in the tropical Pacific (El Niño/La Niña) and other improvements. The forecast data is also available through C3S as part of the multi-model seasonal forecast service that combines data from SEAS5, the UK Met Office and Météo-France.

December

ECMWF to contribute to EU fire project

ECMWF became the computational centre for the Copernicus Emergency Management Service – Fire. ECMWF will provide fire danger calculations from high-resolution and ensemble forecasts up to 15 days ahead on a daily basis. The development of a long-range forecast is also planned and a pre-operational suite will be made available.



Temperature difference between 2017 and 1981-2010

Symposium for Adrian Simmons

A symposium celebrated the lifelong work of ECMWF scientist Adrian Simmons, who has made major contributions to progress in weather forecasting, climate science and atmospheric composition.

2017 extends exceptionally warm period

C3S datasets show temperatures for 2017 were higher than the 1981–2010 climatological average over most regions of the world. They were most above average over parts of the Arctic. 2017 was close to the warmest year on record despite cooling La Niña conditions both early and late in the year over the equatorial eastern Pacific Ocean. The warmest months of 2016 occurred in the declining phase of a strong El Niño, which also influenced temperatures in 2015, making 2017 the warmest year on record that was not influenced by an El Niño.

Advancing weather science

ECMWF carries out world-leading research into all aspects of numerical weather prediction. The advances made are incorporated into operations to improve the Centre's forecasts for the benefit of users. Collaboration with space agencies, national meteorological services and the research community worldwide is a key part of this research effort.

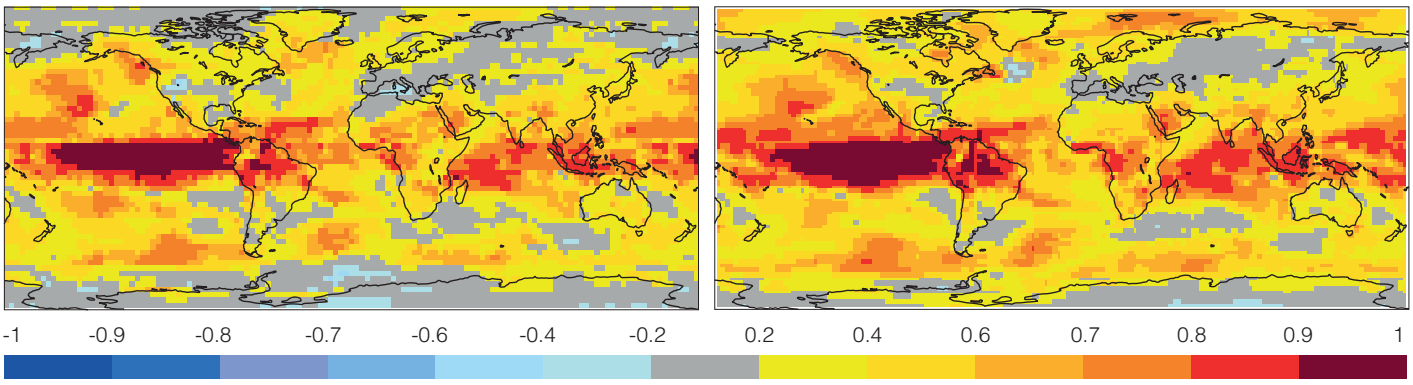
Developing new science takes time. In 2017, ECMWF scientists brought several projects to a successful conclusion, such as the development of a new seasonal forecasting system, SEAS5; the production of a new coupled satellite-era reanalysis; changes to the warm-rain microphysics parametrization to improve the representation of precipitation near land–water boundaries; and a range of improvements in the use of atmospheric in situ observations, including the ability to account for radiosonde drift. Examples of substantial progress in other areas include research into how coupling the atmosphere with the ocean improves tropical cyclone predictions; tests of different ensemble forecast configurations; and the evaluation of a new satellite-based sea-ice thickness product.

SEAS5

In November 2017, ECMWF implemented a new seasonal forecasting system, SEAS5. Seasonal forecasts provide predictions up to 13 months ahead. They describe how the atmospheric, ocean and land surface conditions over particular areas and periods of time are likely to be different from the long-term average. SEAS5 includes several upgrades in the ocean model, atmospheric resolution and land surface initialisation. The changes have led to better predictions in the tropics and the Arctic compared to SEAS5's predecessor, S4.

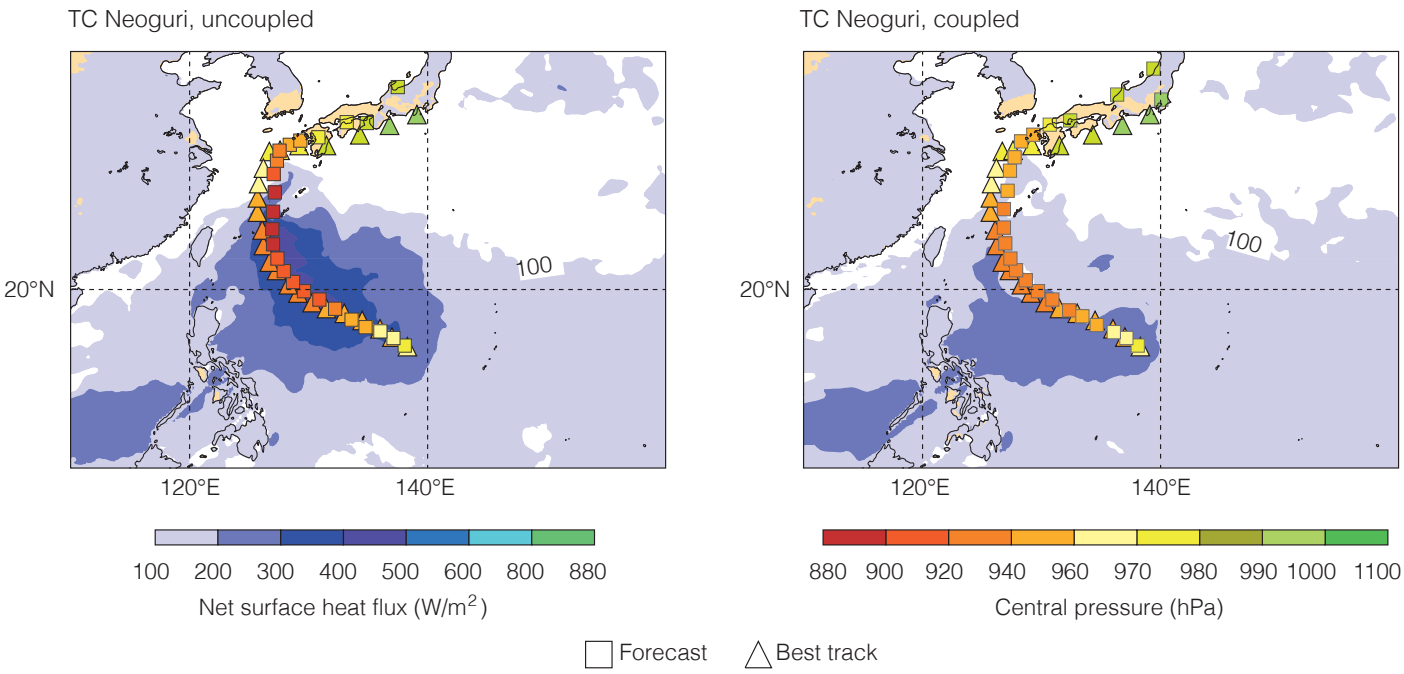
In developing SEAS5, care was taken to move towards a seamless approach to forecasting across timescales, in line with ECMWF's Strategy to 2025. This means that SEAS5 is configured almost identically to extended-range ensemble forecasts, which have lead times of 15 to 45 days. A seamless forecast system makes forecasts more consistent across different time ranges. It also makes it easier to identify and fix problems, to the benefit of forecast quality at all timescales.

> "A seamless forecast system makes forecasts more consistent across different time ranges."



▼ Improved forecast skill

Anomaly correlation for ensemble mean 2-metre temperature predictions for December–January–February from 1 November for S4 (left) and SEAS5 (right). Improvements can be seen in the tropics and the Arctic. Anomaly correlation is a measure of skill. A value of 1 corresponds to a perfect deterministic forecast, while 0 means no skill.

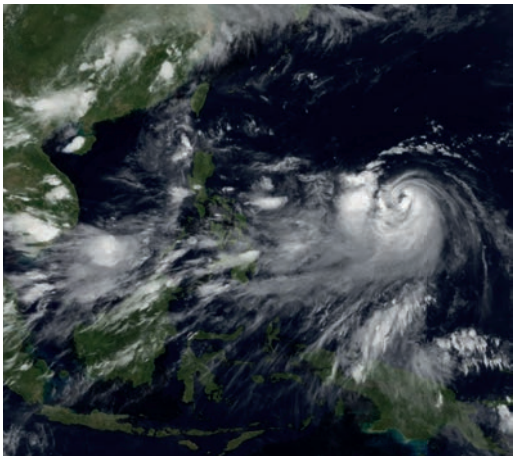


Ocean coupling

Tropical cyclones (TCs) are one of the deadliest weather phenomena, but some of their features can be tricky to predict. Research at ECMWF has shown that interactions between the ocean and the atmosphere can have a decisive influence on the evolution of TC intensity. Heat exchanges between these two Earth system components need to be taken into account to avoid overpredicting TC intensity in some cases.

The main energy source for TCs is heat transport from the ocean. Not coupling the atmosphere and the ocean in the forecast means that the ocean acts as an undiminished source of energy for the atmosphere during the forecast period. This allows TC intensity in the forecast to increase unrealistically if the warm top layer of the ocean is shallow.

Typhoon Neoguri is an example of a TC in which a shallow warm layer in the ocean was quickly depleted, causing Neoguri to develop less deep central pressure than might otherwise be expected. ECMWF's coupled model is able to represent these interactions.



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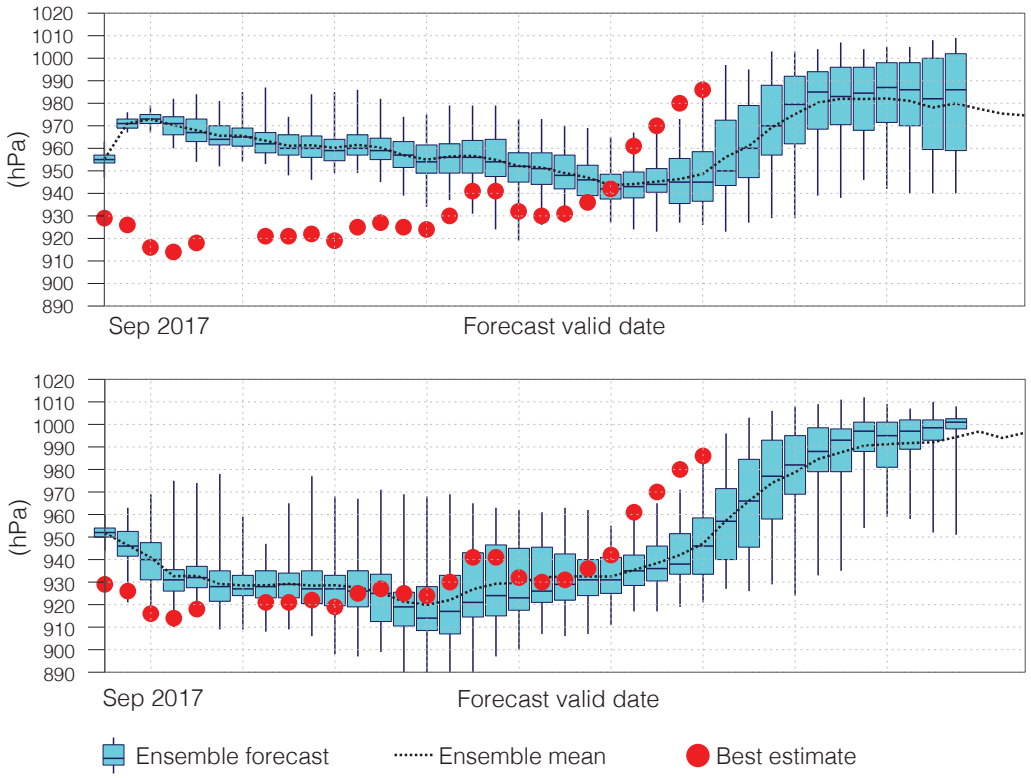
▲ Track and intensity forecasts

Five-day high-resolution track and intensity forecasts (squares) starting on 5 July 2014 together with 'best track' estimates (triangles) and the predicted net surface heat flux (shading) for Typhoon Neoguri using the uncoupled model (left) and the coupled model (right).

◀ Satellite image

Typhoon Neoguri on 4 July 2014.

Advancing weather science



Hurricane Irma intensity forecasts

Forecasts from 5 September of central pressure for Hurricane Irma using the current 18 km operational configuration (top) and a 5 km ensemble (bottom). The higher-resolution forecasts match best-estimate values much better than the operational configuration.

Ensemble configuration

An ensemble forecast is a set of forecasts that represent the range of possible future weather evolutions given the observed current state of the Earth system. A large ensemble size and high spatial resolution are generally advantageous, but they are also computationally expensive.

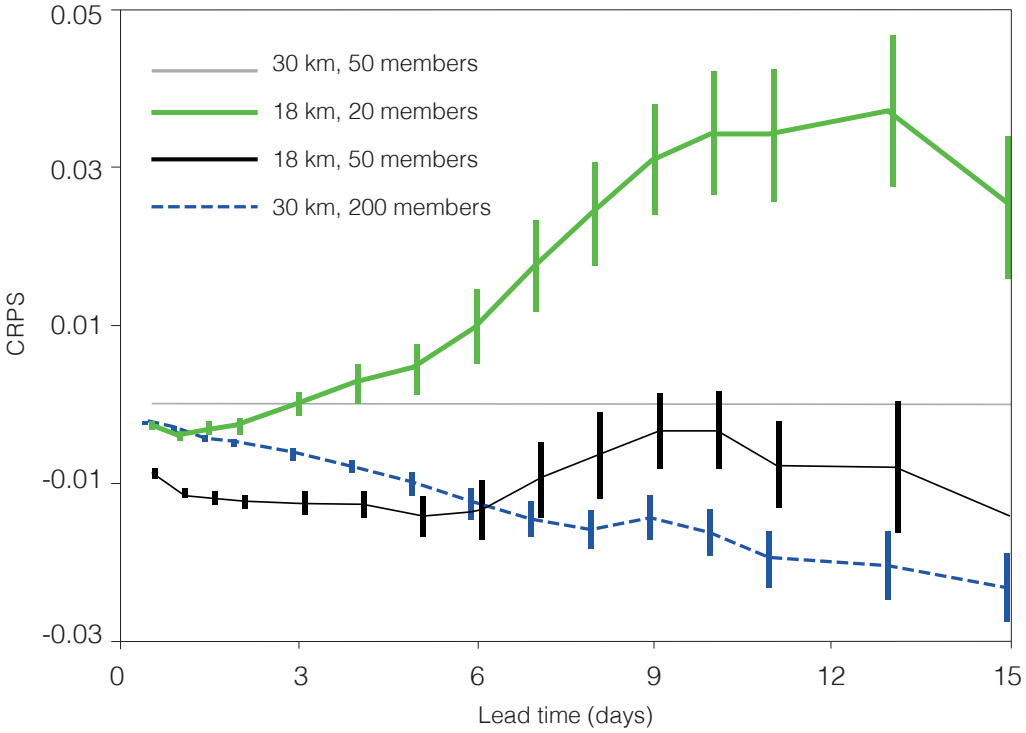
As ECMWF moves towards the goal of 5 km global ensemble forecasts set in its Strategy to 2025, there is a need to investigate the relationship between ensemble size, spatial resolution, forecast quality and computational affordability.

Experiments at ECMWF have confirmed that a 5 km ensemble brings clear benefits compared to today's 18 km ensemble. It would, for example, have produced much better forecasts of the intensity of Hurricane Irma, which struck several Caribbean islands and Florida in September 2017. Severe floods in Livorno, Italy, in September 2017 would also have been better predicted.

Meanwhile, it is not clear that the current operational ensemble size of 50 should be reduced to make global 5 km forecasts affordable. Experiments show that significant reductions in ensemble size are liable to reduce probabilistic skill in the medium range. Conversely, further increases in skill appear possible if ensemble size is increased beyond the current operational configuration.

18→5 km

Experiments have confirmed that a 5 km ensemble brings clear benefits compared to today's 18 km ensemble.



Forecast skill for different ensemble configurations

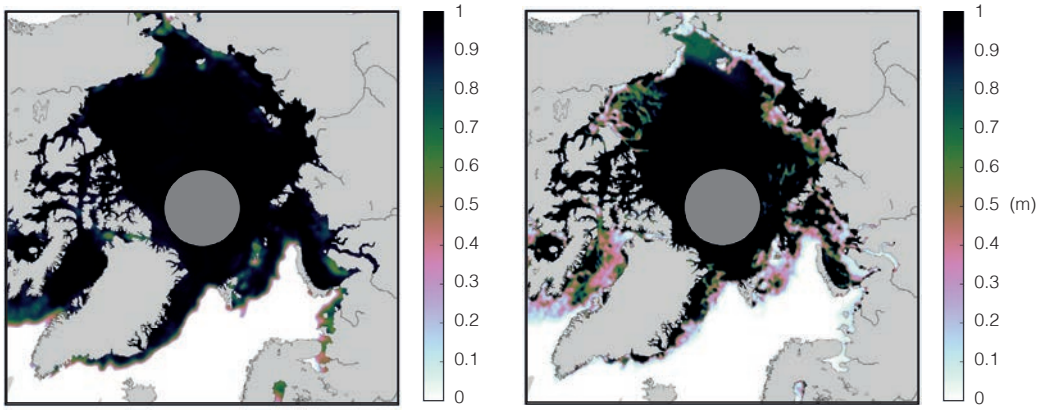
Difference in CRPS (a measure of forecast skill) relative to a 50-member 30 km resolution ensemble, for three different combinations of horizontal resolution and ensemble size. Lower values mean higher relative skill. The black line shows the current operational configuration. The blue line shows that, for some lead times at least, a larger ensemble size can improve medium-range forecast quality even at a lower spatial resolution. The forecasts are for 850 hPa temperature verified against analyses, in the northern extratropics June–July–August 2016.

Thin sea ice

Sea-ice thickness is important for medium-range to seasonal predictions because thin ice evolves much more quickly than thick ice. Small differences in ice thickness at the beginning of summer can also make a large difference to the timing of its complete disappearance during the melt season.

In 2017 ECMWF routinely obtained and processed a product (SMOS-SIT) based on satellite observations for sea-ice thicknesses of up to about 1 metre from the University of Hamburg. This type of innovative product should in the future help ECMWF to improve the representation of Earth system interactions in the Integrated Forecasting System (IFS).

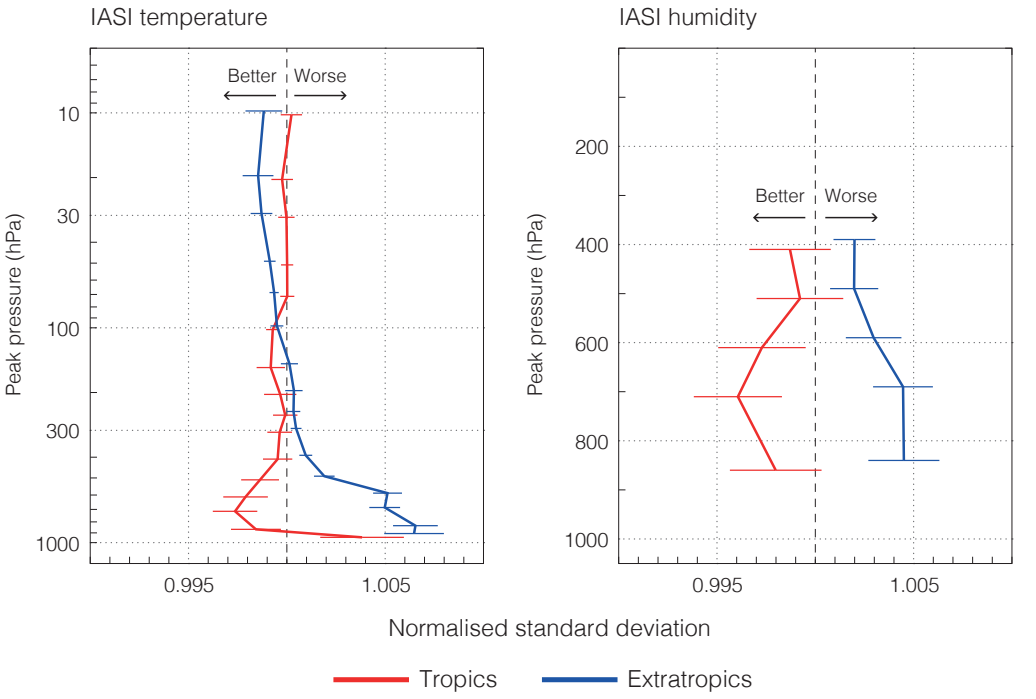
First evaluation results show encouraging similarities between observations and ECMWF's OCEAN5 analysis although there are also some regional discrepancies. The next step would be the development of sea-ice data assimilation schemes which can fully exploit the sea-ice thickness information provided by satellite observations to arrive at an improved sea-ice analysis. This work will provide important building blocks in efforts to improve predictions in the polar regions.



Sea-ice products

Daily-mean fields for 16 April 2017 showing sea-ice concentration from the OSTIA product (left) and sea-ice thickness from the SMOS-SIT product (right). The thickness plot provides a lot more detail on the amount of sea ice in some areas than the sea-ice concentration plot alone. The area around the North Pole is greyed out because of a lack of satellite observations in this region.

Advancing weather science



Differences in background departures

The plots show differences between CERA-SAT and an uncoupled control experiment. Values smaller than one indicate an improved fit of 24-hour forecasts to temperature and humidity observations from the IASI satellite instrument. The comparison spans the full year from September 2015 up to and including August 2016. Bars indicate 95% confidence intervals.

Twenty years of 4D-Var

2017 marked 20 years of ECMWF's use of the 4D-Var data assimilation technique to initialise forecasts. The method is particularly well suited for the assimilation of satellite data and has brought major improvements in forecast skill. In 2017, it was successfully extended to a coupled system in the production of a satellite-era research reanalysis called CERA-SAT.

CERA-SAT reconstructs the state of the atmosphere, the ocean, sea ice, ocean waves and the land surface between 2008 and 2016. It is coupled in that atmospheric, ocean, sea-ice, ocean-wave and land-surface observations are assimilated in a consistent manner. The production of CERA-SAT as part of the EU-funded ERA-CLIM2 project is thus a milestone on the road towards a strategic goal: the implementation of an Earth system approach in all parts of ECMWF's forecasting system.

Experiments show that in the tropics the differences between observations and 24-hour forecasts are generally smaller in CERA-SAT than in uncoupled control experiments, indicating an improved reanalysis. Work is under way to improve results in the extratropics, where CERA-SAT generally performs less well.

> "CERA-SAT is a milestone on the road towards a strategic goal: the implementation of an Earth system approach in all parts of the forecasting system."

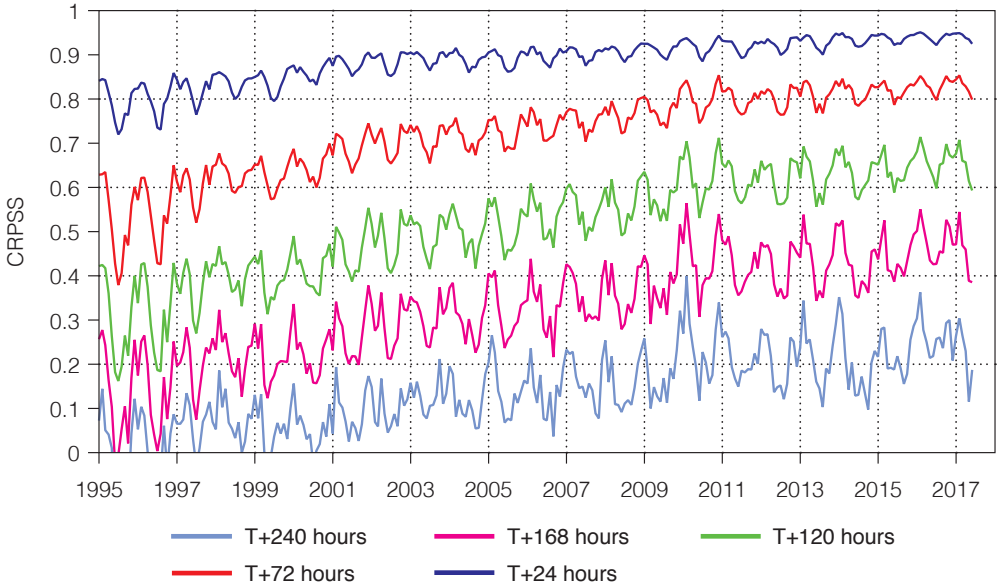
> “Ensemble forecasts can provide indices of the risk of severe events and probabilities of the occurrence of weather events.”

Twenty-five years of ensemble forecasting at ECMWF

2017 was the 25th anniversary of the year when the Centre started to issue operational ensemble forecasts. The availability of such forecasts marked a paradigm shift in weather prediction: for the first time, forecasters and users were provided with reliable and accurate estimates of the range of possible future scenarios, and not just with a single realisation of the future.

Today ensembles are used not just to provide forecasts for the short- and medium-range, the monthly and the seasonal timescale, but also to provide estimates of the initial state of the Earth system. These ensemble-based forecasts and analyses contain more complete information than single, deterministic forecasts. For example, they can provide indices of the risk of severe events; probabilities of the occurrence of weather events; the range of possible values at specific locations; alternative weather scenarios; and weekly-mean anomalies.

Thanks to model upgrades, improvements in the data assimilation system, the use of more observations, and ensemble configuration changes, the performance of ensemble forecasts has increased substantially during the past 25 years.



▲ Ensemble forecast skill evolution

Time evolution, from 1 January 1995 to 2017, of the Continuous Ranked Probability Skill Score (CRPSS) of ensemble forecasts of 500 hPa geopotential height over the northern hemisphere, for lead times of 24 hours, 72 hours, 120 hours, 168 hours and 240 hours. Forecasts are verified against operational analyses. A CRPSS of 1 is the best value possible. The more or less regular pattern of peaks and troughs in each line stems from differences in predictability related to the seasons: winter weather tends to be more predictable than summer weather.

Delivering global predictions

Hurricane Ophelia

In October Hurricane Ophelia transported a mixture of smoke, dust and sea salt aerosol across Europe leading to red skies.

To keep improving forecasts, ECMWF systematically evaluates the performance of its operational forecasts, engages with users and applies the latest scientific advances. Across Europe, the potentially devastating impact of extreme weather such as heatwaves and windstorms was felt keenly in 2017, underlining the importance of improving forecasts to help protect life and property.

In 2017 ECMWF implemented a substantial upgrade of its Integrated Forecasting System (IFS), bringing significant improvements in forecast skill. Cycle 43r3 included changes in the model; in the way observations are used; in software infrastructure; and in the assimilation procedure used to generate the initial conditions for forecasts.

The Centre also extended its monitoring system to cover ocean observations and continues to work closely with the World Meteorological Organization (WMO) on forecast verification and developing the global observing system.

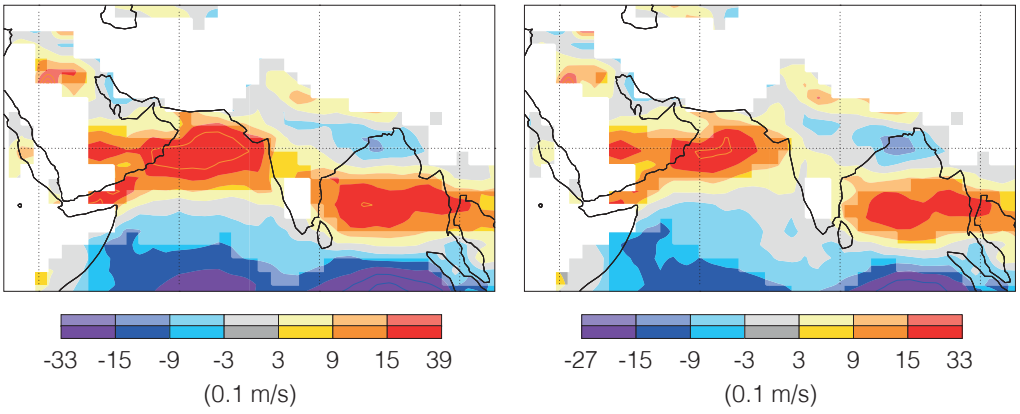
Verification results show that the skill of the Centre's medium-range forecasts, as measured by a set of headline scores, has continued to improve. To help assess progress towards the goals set out in the Centre's Strategy to 2025, two additional headline scores have been agreed for the ensemble forecast.

Timeliness is also important: on 7 March, ECMWF started disseminating medium-range probabilistic forecasts to its users 40 minutes earlier than before. This earlier availability means users in ECMWF's Member and Co-operating States can now use the most recent 0000 UTC forecast in key applications instead of having to rely on the previous day's 1200 UTC forecast.

> The science in Cycle 43r1 contributed to a better representation of Earth system processes.

a) Zonal wind bias (previous)

b) Zonal wind bias (new)



Wind bias

Bias in the day-5 forecast of 925 hPa zonal wind in the Indian monsoon region in summer (June–August) for (a) the previous IFS cycle, 43r1, and (b) IFS Cycle 43r3 with the new aerosol climatology. Saturated colours indicate areas where the signal is significant at the 95% confidence level.

Forecasting system upgrade

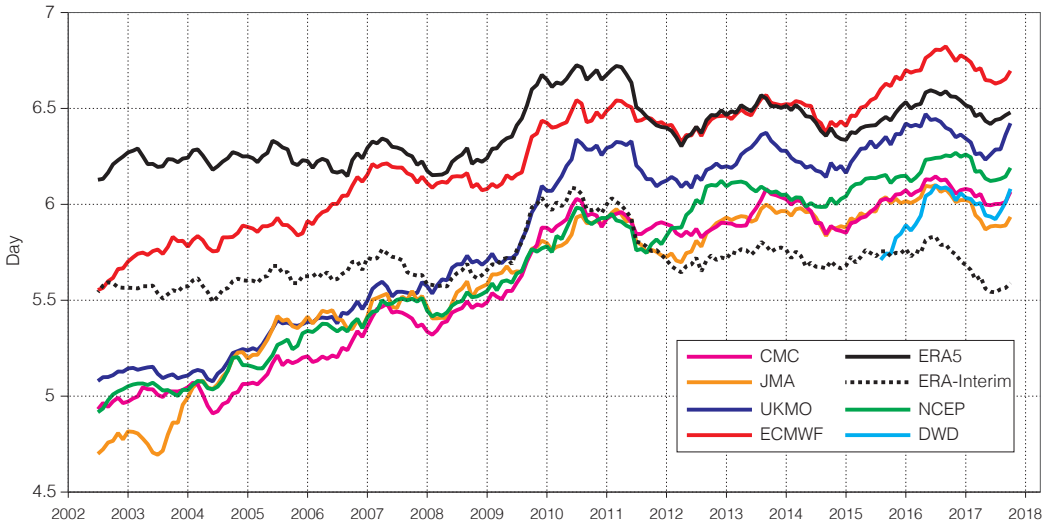
IFS Cycle 43r1 became operational on 11 July, enabling the use of more observations and improving their assimilation. Changes in data assimilation and in the way dropsonde observations are handled improved the accuracy of the initial conditions on which forecasts are based, especially for tropical cyclones. Model changes included a new radiation scheme, improvements in the modelling of convection, and a new aerosol climatology, all contributing to a better representation of Earth system processes. These advances represent essential steps towards the Centre's goals and have led to significant improvements in forecast skill in medium-range and monthly forecasts.

Looking ahead, the implementation of future model upgrades will be streamlined as a result of software infrastructure updates made in this model cycle. Notably, these updates will facilitate further work on single precision, which is expected to make an important contribution to the Centre's Scalability Programme.

New aerosol climatology

A new climatology derived from data provided by the Copernicus Atmosphere Monitoring Service (CAMS) has led to an improved representation of the Indian summer monsoon. A reduction in the absorption of shortwave radiation over Arabia leads to less solar heating and hence a reduction in the strength of the Arabian heat low. This in turn reduces the bias in westerly wind into India by around 25%, which halves the previous overestimate of rainfall over the west coast of India.

Delivering global predictions



Headline score

The chart shows the lead time at which the anomaly correlation for 500 hPa geopotential in the northern hemisphere extratropics drops below 80% in ECMWF's high-resolution forecast (HRES) and in those of other global forecasting centres. ERA-Interim and ERA5 are shown for reference.

Forecast quality

Model upgrades in November 2016 and July 2017 have enabled ECMWF to remain the leading centre in terms of overall medium-range forecast skill. The ERA5 reanalysis produced by the EU-funded Copernicus Climate Change Service now provides a useful benchmark and reference for the identification of interannual variations in predictability, replacing ERA-Interim in this regard.

The resolution upgrade from 32 to 18 km for the ensemble forecast in 2016 contributed to a noticeable increase in skill. Verification scores for precipitation forecasts reached their best-ever levels in 2017, and several Member and Co-operating States reported positive feedback on this improved quality.

Headline scores for surface parameters focus on precipitation for both the high-resolution and ensemble forecast. The 12-month running mean value of the ensemble forecast skill for precipitation continues to be at a CRPSS skill score level of at least 10% out to day 7.

The 12-month running mean value of the ensemble forecast skill for temperature at 850 hPa in the northern hemisphere extratropics is now consistently at a CRPSS skill score level of at least 25% out to 9 days, which is an increase of more than a day over the last decade.

Tropical cyclone track errors were the smallest ever in 2017 for the high-resolution and ensemble forecasts. Improvements are expected in forecasting tropical cyclone intensity in future model cycles.

New headline scores

In April, the ECMWF Technical Advisory Committee (TAC) Subgroup on Verification Measures recommended the introduction of two new headline scores for monitoring ensemble forecast skill in the medium and extended ranges.

The additional score for the medium range will be based on the frequency of large 2 m temperature errors as measured by the continuous ranked probability score (CRPS) exceeding a given threshold. For the extended range, the new headline score will be the skill in predicting weekly means of 2 m temperature anomalies as measured by the ranked probability skill score applied to terciles or higher quantiles. Both scores will be computed for the northern extratropics. The new scores are guided by the needs of our Member and Co-operating States and contribute to the overall evaluation of progress towards ECMWF's strategic goals.

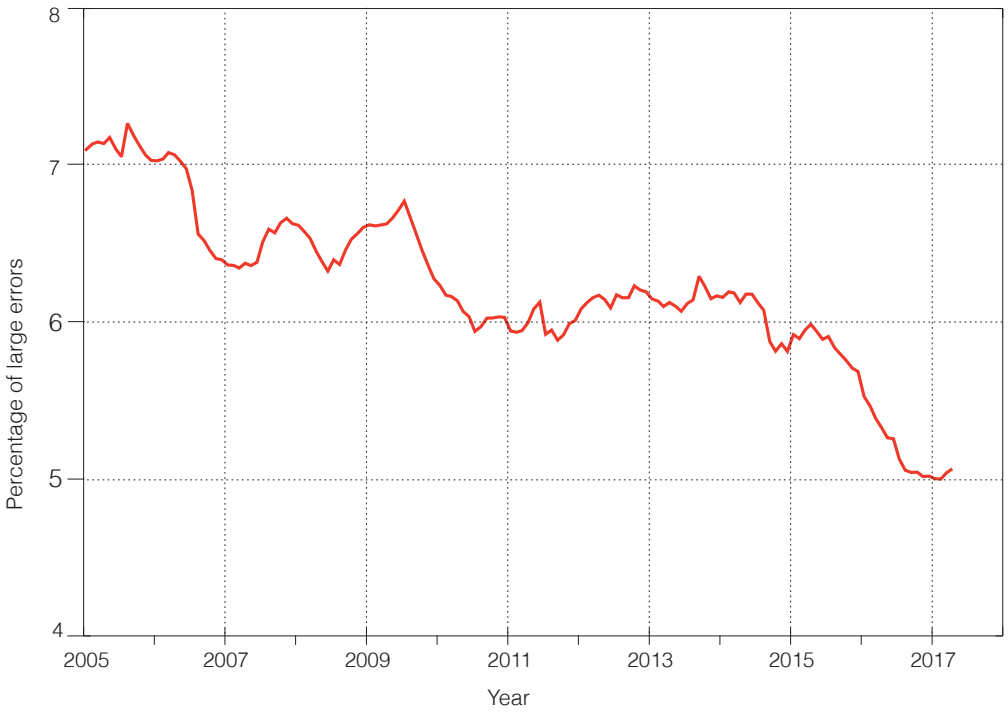
Monitoring and verification

The WMO designated ECMWF as a World Meteorological Centre in May, acknowledging the Centre's compliance with the standards set out in the Global Data-Processing and Forecasting System manual, including for product verification and forecast performance. It also endorsed ECMWF as the Lead Centre for Wave Forecast Verification. ECMWF's main activity will be to collect ocean wave forecasts from global and regional centres and to evaluate them using a common set of observations.

ECMWF is also contributing to a WMO project to develop new near-real-time monitoring for the global observing system, the WIGOS Data Quality Monitoring System (WDQMS). This will provide much more efficient feedback to observation providers through modernised procedures.

To support coupled data assimilation developments, in 2017 ECMWF extended its data monitoring system to cover ocean observations. This will provide vital information on the availability and quality of observations used in the ocean data assimilation system, leading to quick reaction to anomalies in the observations, better understanding of model errors and, ultimately, better Earth system predictions.

> "The new scores measure forecast skill in the medium and extended ranges and were selected as being most relevant to users."



◀ New headline score in the medium range

The plot shows the 12-month running mean percentage of continuous ranked probability score (CRPS) values for 2 m temperature exceeding 5 K at day 5 in the extratropics (poleward of 30° latitude), verified against surface synoptic observations.

Delivering global predictions

Summer heatwave and wildfires in southern Europe

The summer of 2017 was dominated by hot temperatures in southern Europe but cold conditions in the north. Especially during June, the Iberian Peninsula was severely affected by wildfires, and a devastating fire near Coimbra, Portugal, claimed more than 60 lives.

Since 2012 ECMWF has been producing probabilistic fire forecasts as part of the EU-funded activities of the Copernicus Emergency Management Service. The Global ECMWF Fire Forecasting (GEFF) system provides daily global fire danger levels to 10 days ahead. The Instituto Português do Mar e da Atmosfera (IPMA) gained access to GEFF data at the beginning of the summer season. It reported that GEFF products warned days in advance of the establishment of extreme danger conditions in the area and contributed to the better planning and the fast response of the crisis units. More lives might otherwise have been lost.

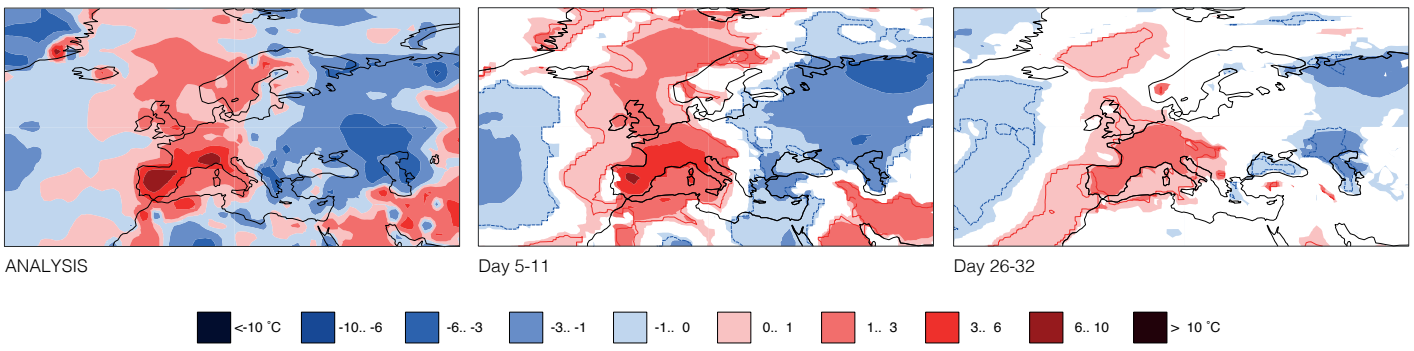
For the week of 12–18 June, there was a significant heatwave over south-western Europe. The forecast captured the structure of the positive temperature anomaly well up to 8–14 days in advance. Even longer forecasts predicted a likelihood for the anomaly, indicating that the initial or boundary conditions of the forecast favoured a warm period.

◀ Fire risk

Extreme heat conditions increase the risk of forest fires.

▼ Temperature anomaly forecasts

The charts show the analysis of two-metre temperature anomalies for 12–18 June 2017 (left) and the forecasts for two-metre temperature anomalies for the same period 5–11 days ahead (middle) and 26-32 days ahead (right).

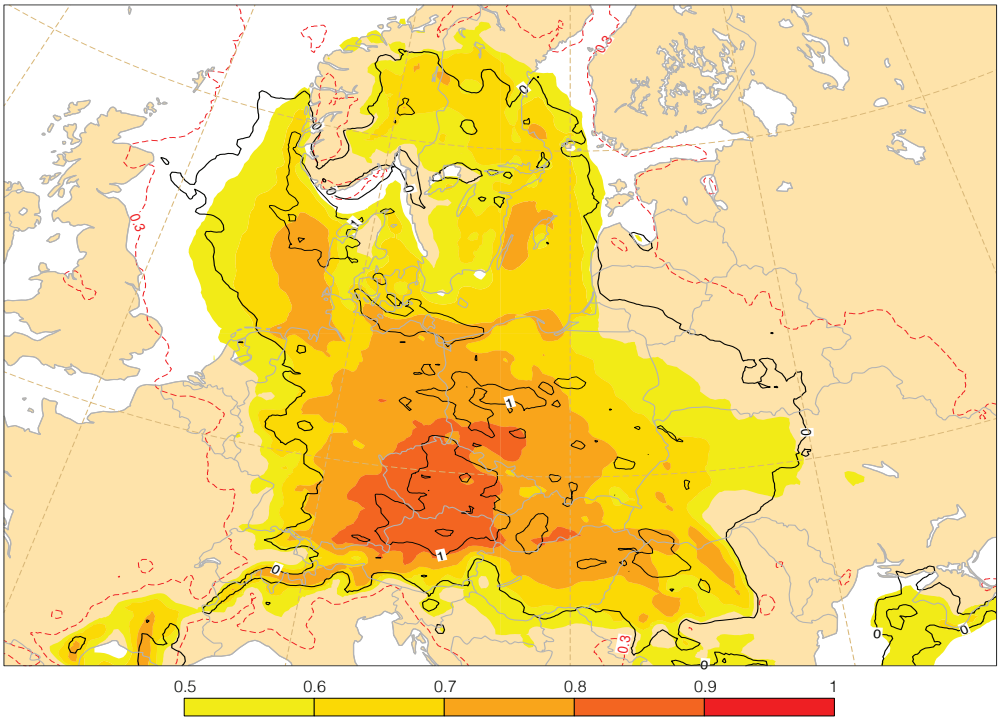


Severe windstorms

On the night of 28 October a deepening cyclone, named Herwart by the Free University of Berlin, moved southeastwards across southern Sweden and the southern Baltic Sea. Within the large circulation of this cyclone, very strong winds developed, most notably over Germany, the Czech Republic and Poland. There were at least four fatalities, damage to trees and buildings and disruption to infrastructure. According to reports in the European Severe Weather Database (ESWD), the Czech Republic was probably worst affected. The short-range Extreme Forecast Index (EFI) for wind gusts agreed well with those reports. Even at a lead time of six days, the ECMWF EFI and Shift of Tails (SOT) clearly highlighted a greatly elevated risk of a severe wind event over a large area. Indeed, the strongest signal in the EFI was centred on the Czech Republic. Throughout the lead-up to this event, ECMWF ensemble forecasts provided a consistent signal for a dangerous windstorm, which grew stronger with time.

Earlier in the year, in August, a severe windstorm hit northern Poland, causing the deaths of five people, significant damage to trees and power disruptions affecting 340,000 households. The risk of severe convective hazards in the affected region was captured in ECMWF medium-range forecasts by the Extreme Forecast index and Shift of Tails product for a composite parameter that combines CAPE and wind shear. However, ECMWF wind gust forecasts failed to predict anything near the observed values.

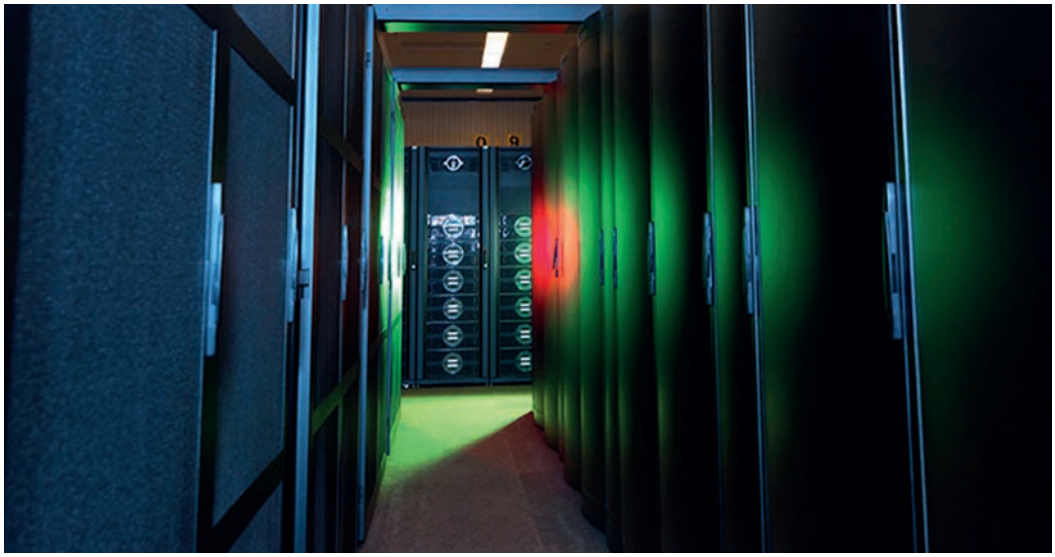
These two cases illustrate very different skill for the same variable (wind gusts). The meteorological conditions behind the two events were very different, and such differences should be borne in mind when interpreting verification results.



◀ Storm Herwart

Ensemble-based forecasts for day 6 of Extreme Forecast Index (EFI, shaded) and Shift of Tails (SOT, black contours) for maximum 10-metre wind gusts during 29 October 2017, highlighting an elevated risk of a severe wind event over a large area.

Sustaining high-performance computing



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> Collaboration between the HPC and Scalability teams aimed to maintain focus on technological advances and sustainable efficiency gains.

In 2017 ECMWF's high-performance computing facility (HPCF) consisted of two Cray XC40s with 260,000 processor cores and more than 900 terabytes of memory. These two supercomputers have been used for operational forecasts since June 2016 and are due to be replaced in 2020, in the new data centre currently being developed in Bologna, Italy.

Providing ECMWF with new supercomputers is a long process which started when our Council approved a substantial additional investment for the next generation of supercomputers at its session in December 2017. The project, known as HPC2020, kicked off with a Request for Information to vendors as part of the business case aiming to ensure that we will get the most suitable technology and best value for money.

We also started to set up a framework contract to purchase the computer storage systems that will support the data centre both in the current location in Reading and in the future location in Bologna.

A research and consultancy company carried out a study in 2017 as part of the Business Case for the investment in HPC2020. The result of the study showed very clearly the large benefits that will be realised in our member countries from investing in the new HPC at ECMWF.

One of the key aspects of 2017 in this field was the necessary and effective close collaboration between HPC and Scalability teams. The aim was to maintain focus on both technological advances and sustainable efficiency gains. The impact of projects funded by the European Union supporting future and emerging technologies

and E-Infrastructures, together with core activities, has been noticeable. Already the first generation of projects like ESCAPE, NextGenIO and ESiWACE have produced significant results, including:

- the first head-to-head comparison of present and future Integrated Forecasting System (IFS) model options on different processor types
- the assessment of full single-precision model runs, and
- the development of a realistic workload simulator for benchmarking.

The second generation of these projects such as ESCAPE-2, MAESTRO and EPiGRAM-HS will continue this legacy in the coming years.

Towards the end of 2017, ECMWF started to develop a proposal for ExtremeEarth, a preparatory action for a Flagship programme with strong involvement from the weather and climate community as well as ECMWF Member and Co-operating States. It will also include expertise from the food, water, energy, health, geophysics and financial risk management sectors. The outcome will be known in late 2018.

On a different note, the year also saw an unusual number of ransomware attacks, infecting thousands of systems around the world. Thanks to the effort of our teams, ECMWF Microsoft Windows systems stayed safe. Despite this success, information security remained a key focus of the Centre.

In addition to significant work on information security policies, work was carried out to develop and deploy a new identity and access management system due to be completed before the move to the new data centre in Bologna.

Special Projects

ECMWF allocates 25% of supercomputing resources to the Centre's Member States. Of these, up to 10% are reserved for Special Projects: experiments or investigations of a scientific or technical nature, undertaken by one or more Member States, likely to be of interest to the general scientific community.

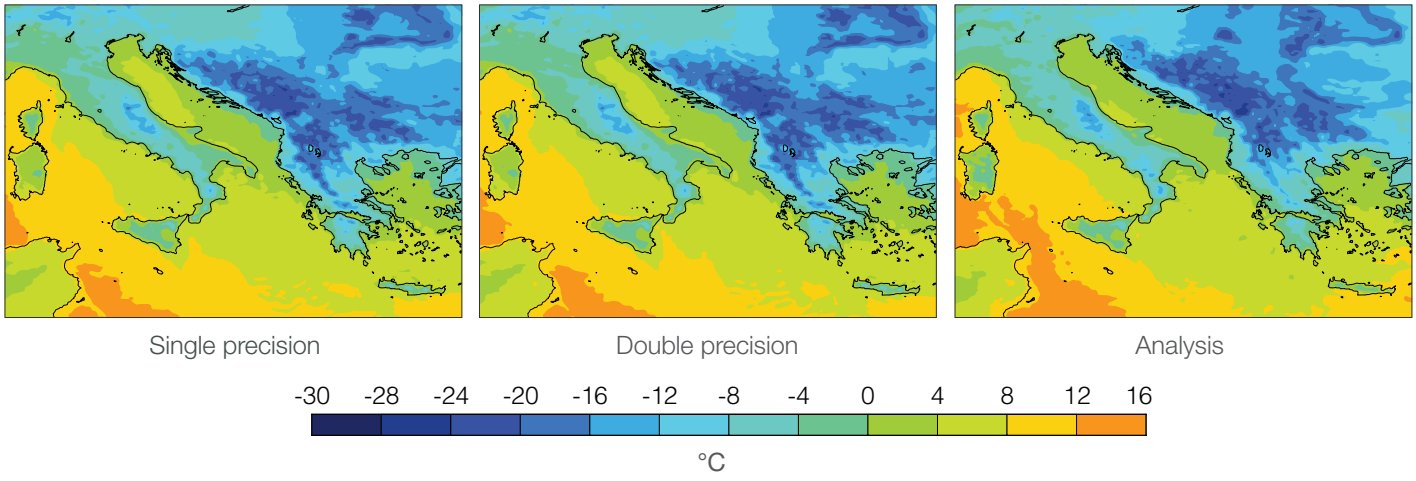
In 2017, 8,250,000,000 System Billing Units (SBUs) and 31,800,000 gigabytes of data storage were made available for this activity.

During the year, 45 projects started in previous years continued, while 25 new Special Projects from 10 different countries were added. These new projects included investigations into the predictability of sea-ice conditions at very small scales; the influence of microphysical processes on the dynamics of weather systems; and perturbation strategies for the development of convection-permitting ensemble forecasting.

25%

of ECMWF's supercomputing resources are allocated to the Centre's Member States.

Sustaining high-performance computing



Single precision to save HPC computing resources

Almost all weather and climate models use double precision on high-performance computing hardware. In this method 64 bits are used to represent each real number and the numbers are represented with at least 15 decimal digits precision. In single precision, 32 bits are used and at least 6 decimal digits are available.

In 2017 ECMWF started experimenting using single precision to improve computational efficiency to make the most of current and future high-performance computing hardware as part of the Scalability Programme. A single precision version of the IFS has been developed and during the year work to refine it continued.

Within the latest IFS cycle (43r3), single precision simulations with the forecast model achieved almost equivalent results for both short- and long-term simulations in research mode. This includes simulations at the resolution of operational forecasts (9 km and 18 km).

However, there are still some hurdles before single precision can be implemented. It was found that mass conservation error was significantly larger in single precision simulations and differences in temperature at 100 hPa as well as in surface temperature were still measurable.

Once this technique is stable, the use of single precision will potentially allow significant savings of computing cost in the near future and an increased throughput on supercomputers.

▲ Single and double precision simulations

Surface temperature in degree Celsius for five-day forecasts for 8 January 2017 0000 UTC. This date is during the European cold wave that caused very low temperatures in Eastern and Central Europe. Results are shown for single precision and double precision simulations at 9 km (TCo1279) resolution (left and middle) and the analysis as a reference (right). Differences between single and double precision are very small.

ecFlow suite for Serbia

In 2017 the Republic Hydrometeorological Service of Serbia (RHMS) set up a suite using ecFlow to run a forecast model using their share of resources on the ECMWF HPCF.

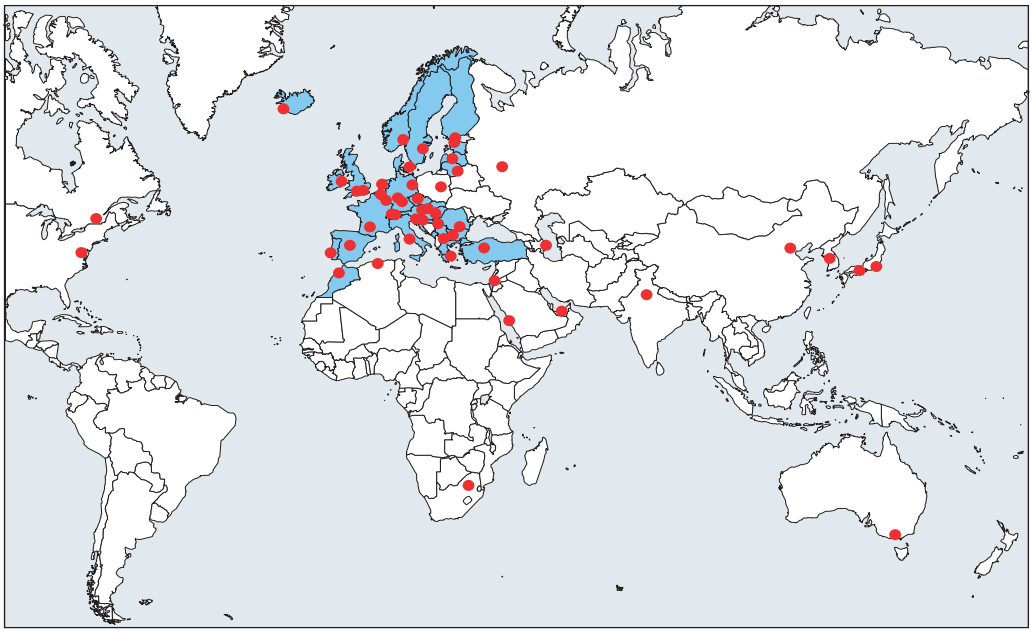
The forecast model is based on the B-grid version of the Nonhydrostatic Multiscale Model. Initial data and lateral boundary conditions are taken from ECMWF high-resolution forecasts and disseminated to the ECMWF HPC. The suite runs twice per day.

The NMM-B regional model has been operational at RHMS since January 2013. Due to the lack of its own computer resources, RHMS could not increase the model resolution and/or ensemble runs. Other operational applications of weather and hydrological forecasts are linked to the NMM-B model, so it needs to be executed in a timely fashion and on a regular basis.

This suite is owned by RHMS and monitored by ECMWF. It was developed under the Framework for Member State time-critical applications.

Regional Meteorological Data Communication Network

The Regional Meteorological Data Communication Network (RMDCN) provides a computer network infrastructure for the meteorological community in World Meteorological Organization (WMO) Region VI and beyond. It was set up in 2000 and provides any-to-any connectivity between more than 50 sites. Among other things, the RMDCN serves to ensure the secure and timely delivery of ECMWF forecasts to its Member States and the exchange of meteorological observations between connected sites. Following an upgrade of the connections of many sites, the network is now nearly complete.



◀ RMDCN global coverage

By the end of 2017, 55 sites were connected to the RMDCN network. The shaded countries indicate ECMWF Member and Co-operating States.

> "The RMDCN serves to ensure the secure and timely delivery of ECMWF forecasts to Member States and the exchange of meteorological observations."

Supporting ECMWF

A winning team

Every year, ECMWF staff take part in the Green Park triathlon to help raise money for Sport Relief.

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Bologna site

Artist's impression of the site proposed in Bologna, Italy, for ECMWF's new data centre.

Supporting ECMWF is about ensuring that the office accommodation, conferencing activities and the high-performance computing facility are all fit for purpose, and that staff are given the means to be as good as they can be.

2017 was an exceptionally busy period in this area, with our Council approving the Italian proposal to host the new data centre in Bologna and the UK Government committing to providing new office and conferencing accommodation by 2023/2024.

A new home for supercomputers

On 22 June 2017, ECMWF's Council approved the proposal made by the Italian Government and the Emilia-Romagna Region to host ECMWF's new data centre in Bologna. After discussions and votes, representatives of ECMWF's Member States were satisfied with the high-level agreement proposed by Italy and approved Bologna as the host city for ECMWF's new data centre.

The Italian proposal had been evaluated as part of an international competition and was judged to best meet ECMWF's requirements. The building is to be delivered to ECMWF by 2019 and will host the Centre's new supercomputers, whilst the Centre's headquarters are to remain in the UK.

The BOND (Bologna: Our New Data centre) programme will remain a high priority for ECMWF in the coming years.

The data centre, however, was not the only relocation project discussed in 2017. Office accommodation was also on the agenda and in December, the UK Government made an official proposal to have the University of Reading as the future long-term location for ECMWF's new office accommodation.

> After an extensive process of evaluation by a panel of international experts and representatives of ECMWF's Member States, Council accepted the proposal made by the Italian Government to host the future data centre in the 'Tecnopolo di Bologna', in the Emilia-Romagna Region of Italy.

▲ Signing agreement

22 June 2017 - ECMWF Director-General Florence Rabier and Col. Silvio Cau, the Head of the Italian national meteorological service, sign the high-level agreement on the data centre.

Supporting ECMWF

> The Graduate Training Programme is an important aspect of ECMWF's strong scientific cooperation with Member and Co-operating States.

▲ **Weather discussion**
Weekly weather discussion in ECMWF's Weather Room.

Staff and funding

ECMWF is of course and above all its staff, who in 2017 came from over 30 countries and included graduate trainees from Hungary, Serbia, Sweden, Ireland and Croatia, and visiting scientists, including two from China. This workforce was enriched by the work of our Fellows, whose contributions help advance critical areas of science.

The financial position of ECMWF remains positive and continues to be influenced by the ongoing success of ECMWF's forecasting, which in turn has contributed to an increase in the sale of ECMWF data and products; and by the high volatility levels in the sterling/euro exchange rate, caused in part by political uncertainty over Brexit.

The implementation of a new Enterprise Resource Planning (ERP) system, which started in 2016, will simplify and automate many of the administrative processes at ECMWF. The design phase was completed in 2017 and the ERP project team is now working with external consultants to deploy core functionalities. HR, Finance and Payroll will be the first areas to go live in 2018, additional elements will be gradually rolled out at a later stage. This will bring ECMWF a step closer to the vision of a paperless and streamlined central information hub.

© Florian Rathgeber

▲ **Life at ECMWF**
Regular internal and external events provide opportunities for staff to network and share experiences.

◀ **Graduate Trainees**
Graduate Trainees from the national meteorological services of Croatia, Hungary and Serbia.

European investment in ECMWF

The 34 Member and Co-operating states of ECMWF are the core source of finance for the Centre, with contributions totalling £43.5 million.

External organisations support both core research and the complementary goals of the centre with funding of £42.8 million, while revenue from sales of data and products provide additional income of over £7.8 million.

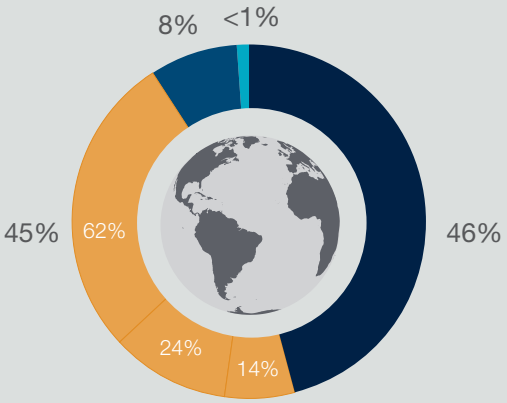
ECMWF continued to invest in its staff, infrastructure and systems to provide the highest quality products to its Member and Co-operating States. The main areas of expenditure are summarised below, and include capital investment of £0.9 million, principally for IT and infrastructure.

The main areas of expenditure related to remuneration and related items (£23.3 million), computer expenses (£19.9 million), pension schemes (£10.5 million), electricity (£3.0 million) and other operating activities (£5.4 million). Costs associated with externally funded projects amounted to £35.6 million and net finance costs were £4.2 million.

ECMWF's budget remains on a cash basis and the Financial Statements include a reconciliation of the results under IPSAS and in cash terms. Under cash accounting, the Centre generated a surplus of £3.1 million in 2017, which Council subsequently approved for use in the Data Centre project.

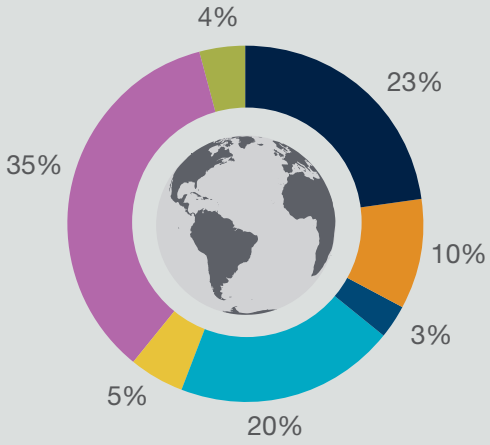
Note: all numbers exclude Centre tax.

Funding



- Member & Co-operating States' contributions
- Externally funded income
  - 14% Third-party projects
  - 24% Copernicus
  - 62% Administered on behalf of the EU
- Sales of forecasts and data
- Other operating revenue

Costs



- Personnel costs
- Pension and post-employment benefits
- Electricity expenditure
- Computer expenditure
- Other operating expenditure
- Externally funded expenditure
- Net finance costs

Serving Member and Co-operating States

◀ Annual Seminar 2017

The Seminar marked 25 years of ensemble prediction at ECMWF, with a keynote address from Eugenia Kalnay, University of Maryland (below).

ECMWF continued to make progress in serving its Member and Co-operating States through enhanced training, forecast outputs, computer services and data delivery. Workshops and other collaborations continued to bring benefits.

ECMWF also serves its community through its contribution to the EU Copernicus Services, which deliver open and free environmental information.

Making deliverables and expertise available

2017 saw an active programme of visits and meetings with our Member and Co-operating States. Highly productive, these activities provide the opportunity for exchanging information on developments and plans for the future.

We continued to ensure efficient access to ECMWF products and computing facilities for our Member and Co-operating States. Developments included locating modules of our in-house dissemination software 'Data Mover' at remote centres to ensure ongoing reliability and speed of delivery, and upgrades to ecgate, which gives users access to ECMWF's computing architecture.

A working group was set up to consider cloud computing and big data. These are key issues which cut across several vital functions of the Centre, and could offer Member States wider potential for serving their own end-users.

The Annual Seminar has always been ECMWF's flagship educational event, but 2017's event also carried an emotional dimension as it was marking 25 years of ensemble prediction at ECMWF. A large number of speakers and participants, both on-site and remote, took part and added their expertise and experience to what was a great opportunity to discuss the future of ensemble prediction. A range of other meetings such as 'Python frameworks for Earth system sciences' and a joint workshop with ESA on 'Using low frequency passive microwave measurements in research and operational applications' continued to help ECMWF build on its science through collaboration with delegates from around the world.

In 2017 ECMWF courses trained over 300 participants. In response to requests from Member States, we redesigned our courses to teach more participants with less on-site and staff time. For example, we have created a three-day blended course on the 'Use and interpretation of ECMWF products' which covers similar material to the 5-day on-site version. Key to these improvements are new eLearning modules and other types of online self-study. An initial set of eLearning modules was published on the website, and Member and Co-operating States can also include them in their own training materials.

ECMWF is providing access to a specialised dataset for the WMO Year of Polar Prediction and other data for WMO members. Our WMO and ECMWF Fellowship programmes continued to bring tangible benefits in line with the ECMWF Strategy.

Progress has been made towards the operational implementation of products from the ECMWF ensemble forecast (ENS) to assist in the key area of severe weather prediction. A new map layer went into ecCharts to show the most probable instantaneous precipitation type (rain, snow, freezing rain, dry etc.) and its probability of occurrence at different lead times. Most of this work has been funded by the H2020 ANYWHERE project. We have also developed forecasts of point-rainfall by post-processing ENS gridbox output to take account of sub-grid scale variability and biases. One important application will be within the Global Flood Awareness System (GloFAS), for flash flood prediction. Other new products have been added regularly to ecCharts, including cloud base height and 2m mean temperature over an interval.

Delivery of forecast products to Member and Co-operating States relies on specialised ECMWF software. Software updates have benefited from contributions received from Member and Co-operating States. ECMWF has released other updates to its standard packages for ecCodes and Metview. A key milestone was the beta release of a new interpolation library called Meteorological Interpolation and Regridding (MIR), which will facilitate scalability improvements and other additional features.

"New products have been added regularly to ecCharts, including cloud base height and 2m mean temperature."

300

In 2017 ECMWF courses trained over 300 participants.

Serving Member and Co-operating States

▲ **Working together**

Twenty teams worked day and night at the open data hackathon (top left); ECMWF Fellows Heini Wernli (top right) and Daniel Jacob (bottom right).

Open data week

Between 28 February and 5 March, ECMWF held a week of events focusing on freely available data, scheduled to coincide with International Open Data Day. Three events looked at key issues surrounding open data: the Workshop on Meteorological Operational Systems (MOS), organised biennially by ECMWF, focused on how to serve large amounts of open data and make them easily accessible; a data hackathon where 70 developers, scientists and data enthusiasts explored uses of freely available data from ECMWF; and a workshop which discussed how to improve the socio-economic impact of numerical weather prediction.

ECMWF Fellows

In addition to the WMO Fellowship programme, ECMWF also appoints its own Fellows to strengthen our relationship with exceptional individuals working in scientific and development areas relevant to the strategic goals of ECMWF. Work with our two most recently appointed Fellows (Heini Wernli, ETH Zurich and Daniel Jacob, Harvard University) is starting to bear fruit. For example, ECMWF is working with Heini Wernli on warm conveyor belts (WCBs), which are regions of ascending air, generally ahead of a cold front. WCBs can be precursors for regime changes, such as the development of blocked conditions over Europe, act to enhance medium-range forecast uncertainty and lead to severe precipitation.

Daniel Jacob is working on innovative ways of assessing errors associated with long-range transport in models which could be tested within the ECMWF Integrated Forecasting System (IFS).

◀ Sentinel-5P

Developed by ESA and launched on 13 October 2017, this satellite will make a vital contribution to the ECMWF-run EU-funded Copernicus Atmosphere Monitoring Service (CAMS) by measuring the composition of the atmosphere.

Partnerships with space agencies

Our work with space agencies goes beyond the provision of data and collaborative development of instruments, extending also to educational activities.

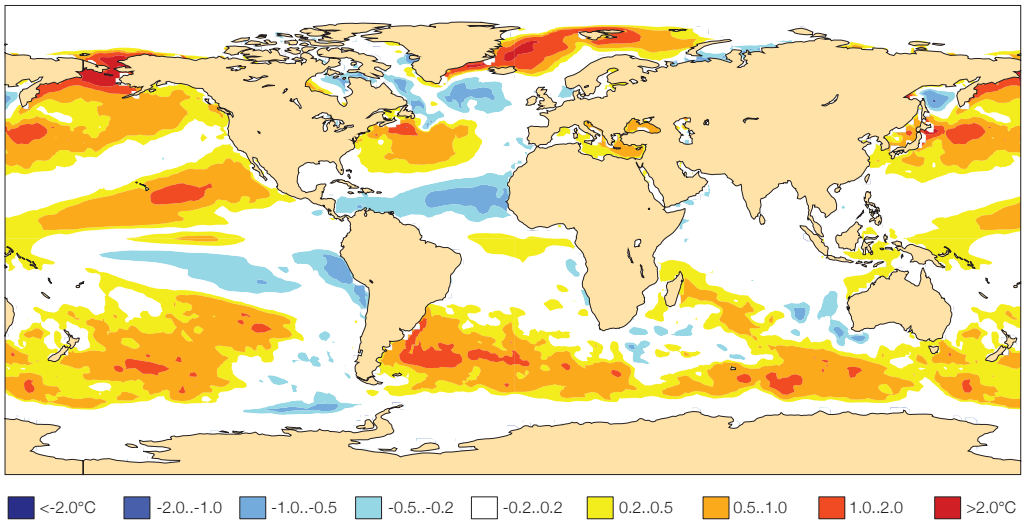
In particular, we organised a workshop with the EUMETSAT NWP-Satellite Application Facility in May to assess the state of readiness ahead of the launch of the METEOSAT Third-Generation Geostationary satellite (MTG). MTG will provide unprecedented observations with potentially enormous impacts on analyses and forecasts, but the incorporation of such data represents significant scientific and technical challenges. The workshop looked at the latest progress in instrument calibration and spectral characterisation, advances in radiative transfer modelling and the various assimilation strategies being considered to exploit this unique and exciting source of observations.

Our collaboration with ESA is also growing stronger, with the advent of the Copernicus Programme in particular.

▲ Satellite observations workshop

Breakout session in the ‘Assimilation of hyper-spectral geostationary satellite observations’ workshop organised in partnership with EUMETSAT (May 2017).

Serving Member and Co-operating States



Seasonal forecasts

The proof-of-concept graphical products from the C3S multi-model seasonal forecast suite include forecasts for mean sea-surface temperature anomaly, based on a combination of three models from the UK Met Office, Météo-France and ECMWF.

Delivering environmental information

2017 marked ten years of daily atmospheric composition forecasts at ECMWF, now run operationally through the Copernicus Atmospheric Monitoring Service (CAMS). CAMS underwent a number of upgrades through the year, and the first CAMS reanalysis was produced covering the period from 2003 to present. Information on the emissions and smoke transport from devastating wildfires in Chile in January 2017 was provided by CAMS.

A significant milestone was achieved early in November when the new ECMWF seasonal forecast system (SEAS5) became part of the Copernicus Climate Change Service (C3S) multi-model seasonal forecast suite. Forecast products are based on input from three core providers: ECMWF, UK Met Office and Météo-France. The current proof-of-concept phase includes graphical forecast products for air and sea-surface temperature, mean sea level pressure and precipitation; the forecasts are updated every month and cover time ranges up to 13 months. SEAS5 products are available to Member and Co-operating States ahead of their release through C3S.

Part of the ERA5 reanalysis was also released.

Agreement was reached on the implementation of the Copernicus Data and Information Access Services (DIAS), which will make Copernicus information available to users through a cloud-based architecture. The work will be done collaboratively between ECMWF, EUMETSAT and Mercator Ocean.

ECMWF is leading a new initiative to explore the development of a European system to monitor human-related carbon dioxide (CO_2) emissions across the world. Such capacity is vital to support Europe's leading role in worldwide action to address climate change. The CO_2 Human Emissions (CHE) project started on 1 October 2017 and brings together a consortium of 22 European partners. It will last for over 3 years and act as a bridge between the European Commission and its CO_2 Task Forces, space agencies and related industries, the CO_2 science community, and the Copernicus Services.

> The ERA5 global climate reanalysis is now in continuous production.

CAMS upgrade

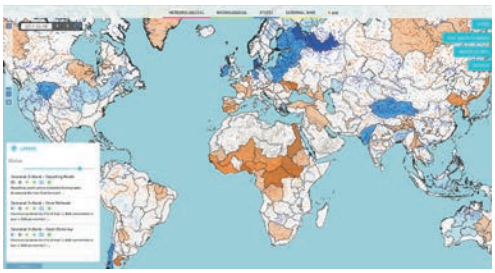
The main objective of the CAMS scientific work performed at ECMWF is to continually develop and upgrade the configuration of the IFS used to produce global analyses and forecasts of atmospheric composition.

Improvements in 2017 included the incorporation of new satellite data: aerosol observations from the Polar Multi-Sensor Aerosol Product provided by EUMETSAT and ozone observations from the Ozone Mapping Profiler Suite provided by NOAA through EUMETSAT's third-party data programme. The aerosol module was upgraded to take into account interactions with gases leading to improvements in aerosol forecasts. Improvements were also seen in the UV forecasts.

ERA5

The ERA5 global climate reanalysis, being developed as part of the C3S, is in continuous production. In July, ERA5 data for the period from 2010 to 2016 were released. During 2017, new ERA5 production streams were added to cover the 1980s and 1990s, in addition to production streams covering the periods from January 1999, from January 2009 and a 'near-real-time' (NRT) stream initiated from December 2014. Atlantic hurricanes which occurred in 2017 were well captured by ERA5 as well as the exceptionally weak Antarctic ozone hole.

C3S reanalysis products are now considered as important scientific inputs to the State of the Climate assessment by the WMO and are contributing to the Global Climate Observing System (GCOS) Implementation Plan.



www.globalfloods.eu

◀ GloFAS

The GloFAS web interface gives access to the seasonal river flow outlook, indicating the maximum probability of higher or lower than normal river flow during the four-month forecast horizon, for the global river network.

Copernicus Emergency Management Service – Early Warning Systems (CEMS-EWS)

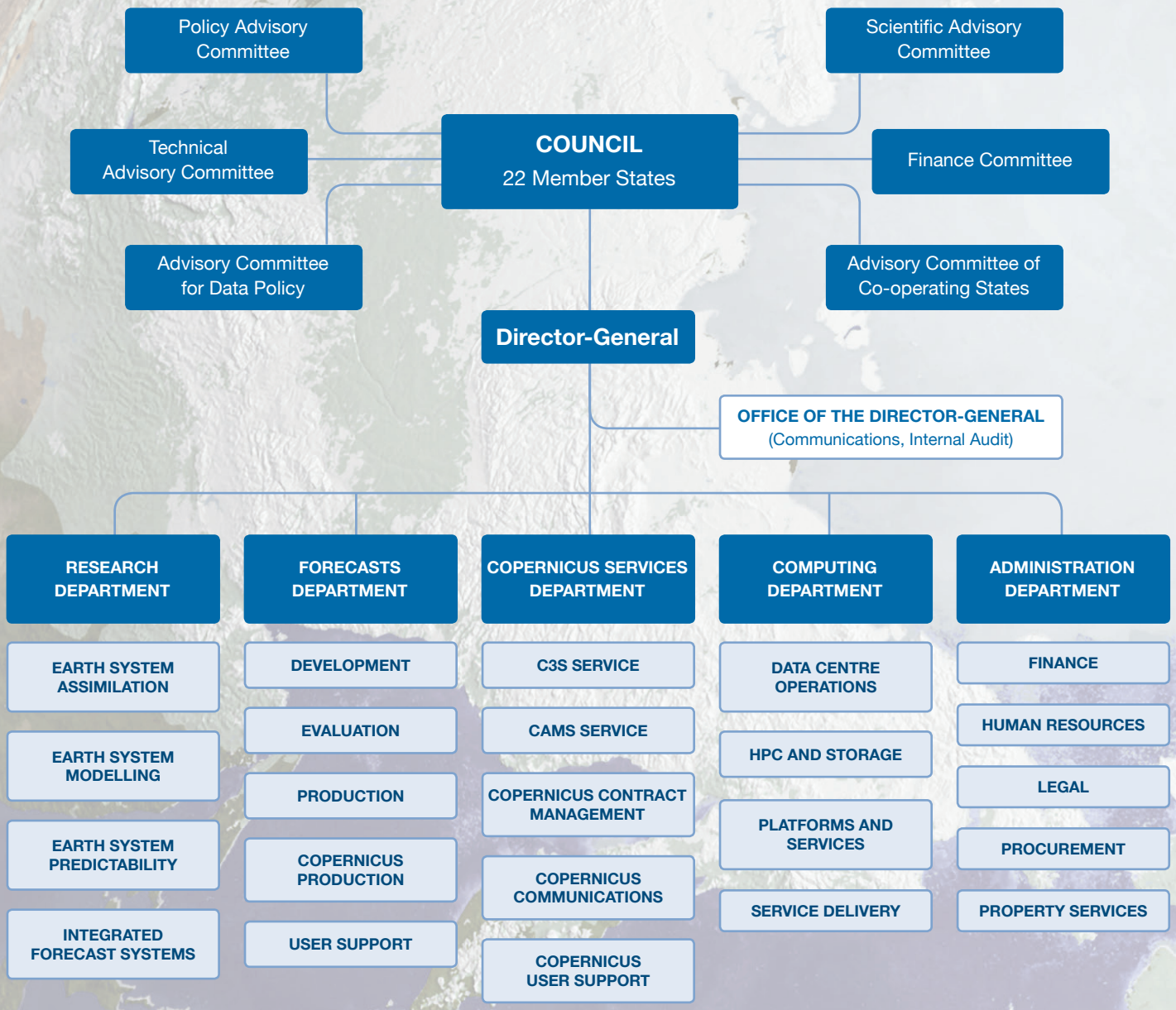
In 2017 ECMWF launched the first global-scale hydrological seasonal forecast for the GloFAS element of the Copernicus Emergency Management Service – Early Warning Systems (CEMS-EWS) and contributed to other improvements in existing CEMS-EWS products. GloFAS seasonal was developed jointly with the University of Reading.

Collaboration has continued between ECMWF and external partners through training, capacity building and data exchange. This includes partnerships with national and international organisations to support early warning and humanitarian action.

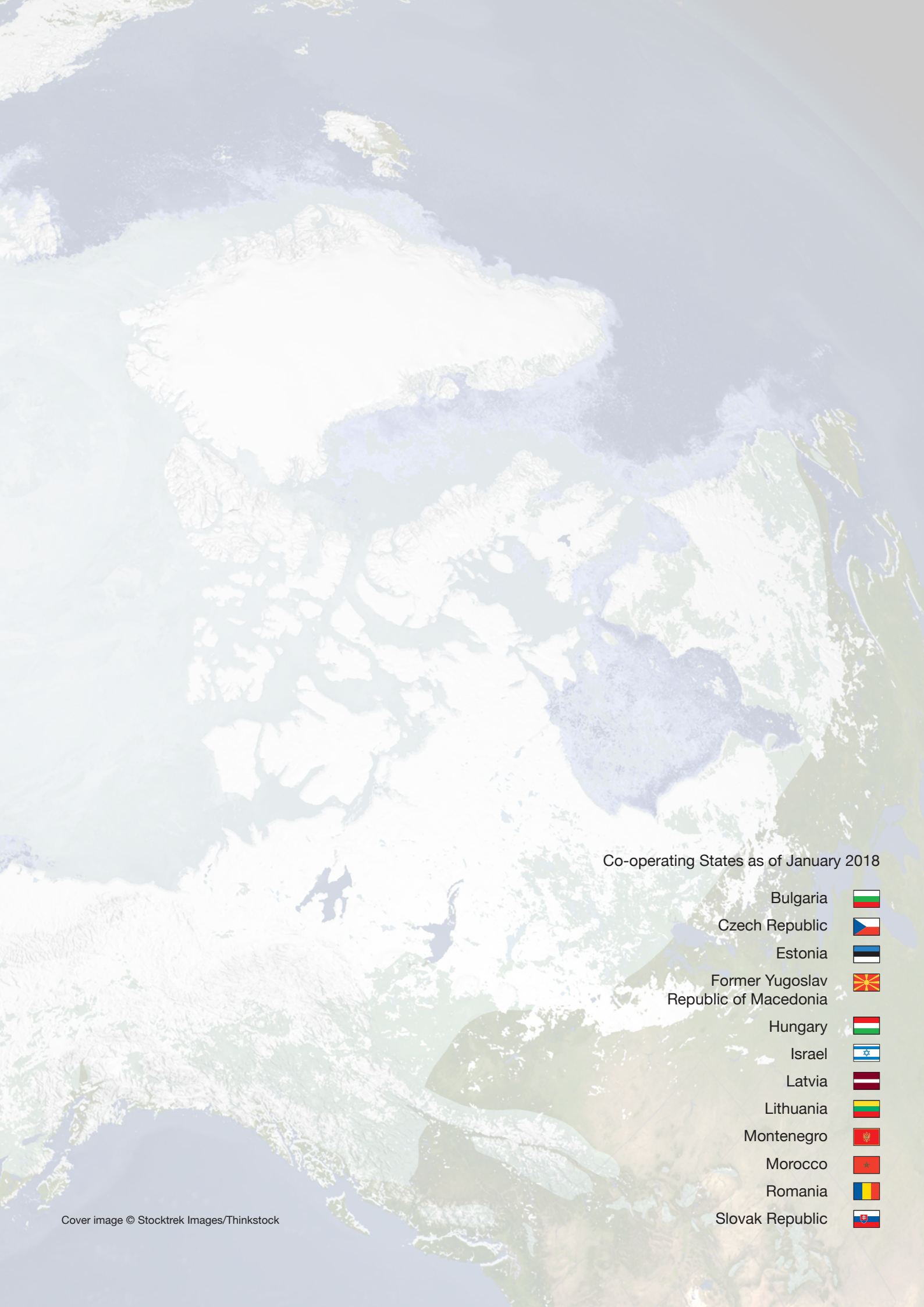
Copernicus fire danger reanalysis products from the Global ECMWF Fire Forecast (GEFF) system were made available for download through the ECMWF public dataset web interface. The products were developed at ECMWF over the last three years as part of CEMS.

After a preliminary trial service, ECMWF was awarded the provision of fire forecasts for CEMS in 2017, which will be undertaken in collaboration with Météo-France. This makes ECMWF the computational centre for both CEMS-Fire and CEMS-Flood.

How we work



Organisation of ECMWF at June 2018



Co-operating States as of January 2018

Bulgaria

Czech Republic

Estonia

Former Yugoslav Republic of Macedonia

Hungary

Israel

Latvia

Lithuania

Montenegro

Morocco

Romania

Slovak Republic

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