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METEOROLOGY

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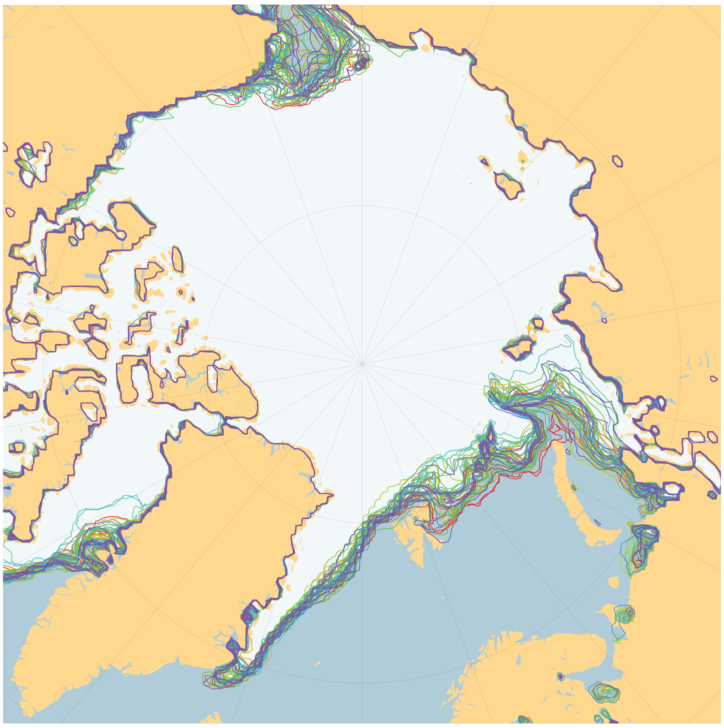

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New IFS cycle brings sea-ice coupling and higher ocean resolution

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On 22 November 2016, ECMWF implemented a new version of its Integrated Forecasting System (IFS Cycle 43r1), which for the first time includes an interactive sea-ice model in the medium-range/monthly ensemble forecast (ENS). Other key features include a four times finer horizontal resolution in the ocean model and the use of a new, higher-resolution ocean ensemble of analyses and reanalyses, ORAS5. IFS Cycle 43r1 also brings changes in the use of observations, data assimilation and modelling, and it introduces a range of new parameters. The various changes and upgrades have led to significant improvements in forecast quality.

Dynamic sea ice

The interactive sea-ice model LIM2, the Louvain-la-Neuve Sea Ice Model developed at the Belgian Université catholique de Louvain, has been implemented, allowing sea-ice cover to respond to changes in the atmosphere and ocean states. This allows, for example, for the melting of sea ice in ENS during atmospheric warming in spring, and in general it enables a more accurate interaction between sea ice, ocean and atmosphere. LIM2 is part of the NEMO (Nucleus for European Modelling of the Ocean) modelling framework also used at ECMWF to model the ocean. The ENS ocean and sea-ice initial conditions are provided by the new ocean analysis and reanalysis ensemble (ORAS5), which uses the new ocean model described below and a revised ensemble perturbation method. ORAS5 has been running in parallel to ORAS4 since August 2016 and covers the period 1975 to the present.

Figure 1 shows an example of the evolution of sea ice in the ENS. Figure 1a shows the five sea-ice initial conditions which are distributed across the 51 ensemble members to help initialise the ENS. The five initial conditions are generated by the new ORAS5 ensemble of ocean analyses. Figure 1b shows 23-day forecasts and the corresponding control (ORAS5 member-0) analysis. The figure shows that the sea-ice edge evolves in the forecast, expanding to cover a larger area. It also shows that there is a degree of uncertainty in the prediction, with some areas characterised by a larger spread among the 51 forecasts. Finally, it shows that the verifying analysis is almost everywhere included in the range spanned by the ensemble.

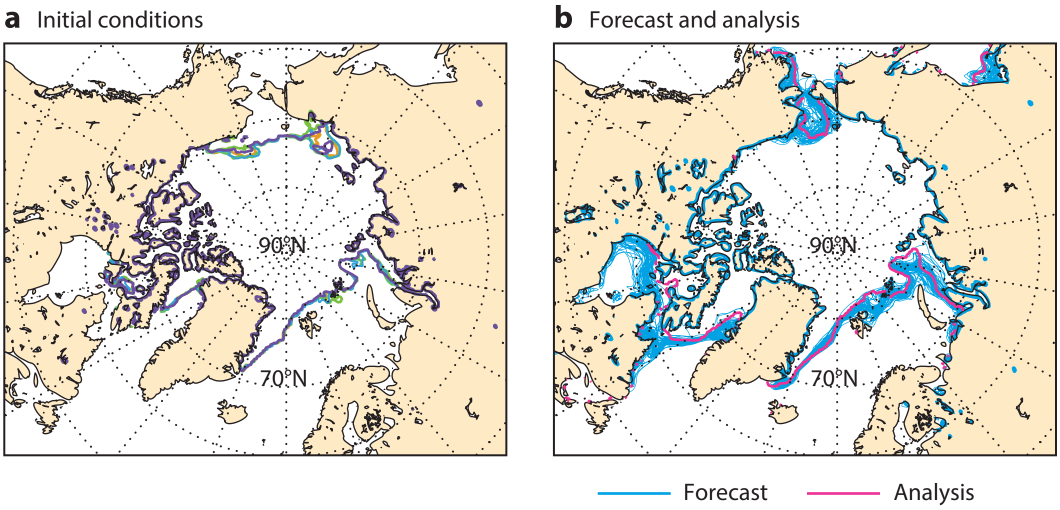

Figure 1 Forecasts and analyses of sea-ice edge, showing (a) the five analyses of the ORAS5 ensemble of analyses, used to initialise the ECMWF medium-range/monthly ensemble on 7 November 2016 at 00 UTC and (b) the 51 ENS 23-day forecasts for the sea-ice edge on 30 November 2016 and the corresponding sea-ice analysis.

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Higher ocean resolution

With this cycle upgrade, the ENS sees a major upgrade in the NEMO consortium's ocean model: the resolution has been increased from 1 degree and 42 layers to 0.25 degrees and 75 layers, the ORCA025z75 ocean model configuration based on the configuration developed by the DRAKKAR group. The increase in vertical resolution is particularly large in the uppermost part of the ocean, with an increase in the number of levels in the first 50 metres from 5 to 18. The horizontal resolution increase means that small-scale ocean circulation features are better captured and coastlines and bathymetry are better resolved than previously, as shown in Figure 2. The vertical resolution increase means that the diurnal cycle of sea-surface temperatures (SST) is much better captured, with a 1-metre top level in the new configuration compared to the previous 10-metre top level. The SST continues to be partially coupled to the atmosphere for the first week. The ocean upgrade makes the ocean more responsive to changes in the atmospheric state and leads to a larger ensemble spread due to more variability in the ocean.

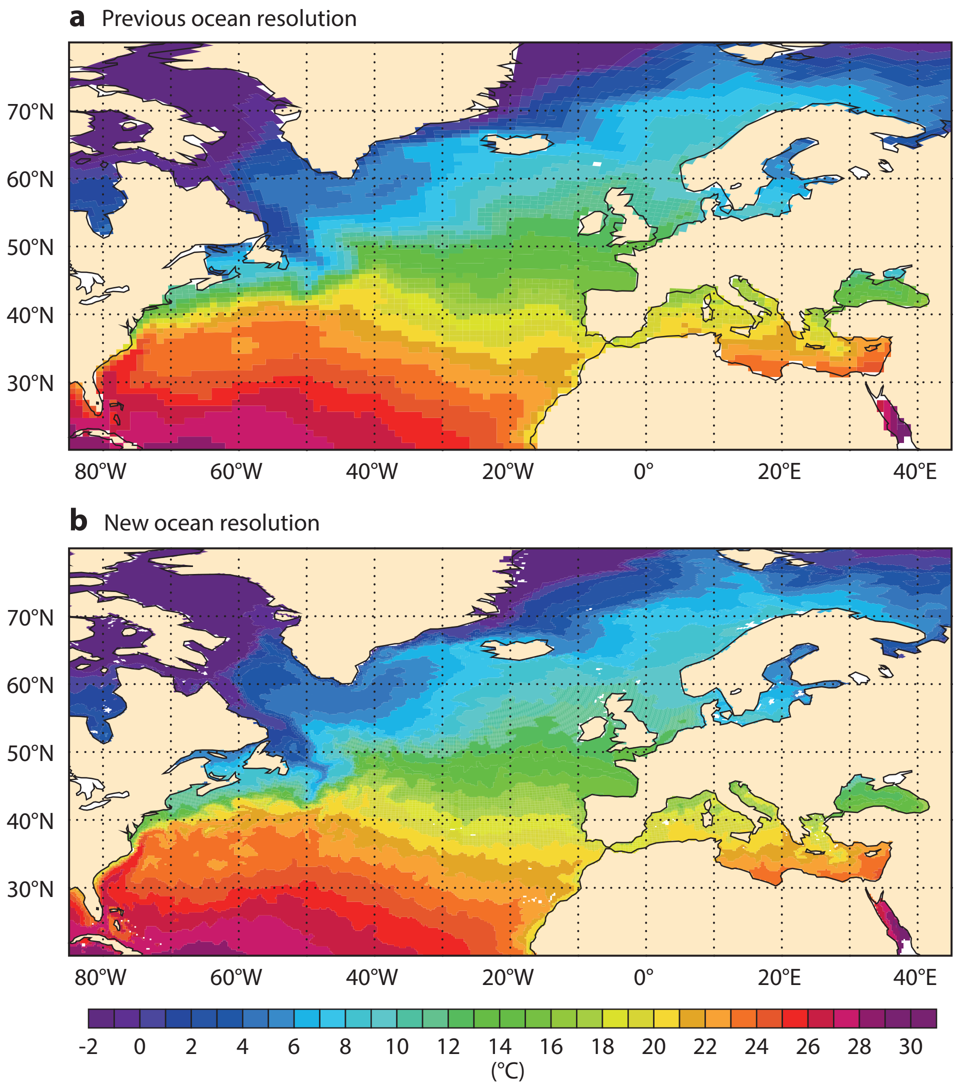

Figure 2 The higher ocean resolution for ensemble forecasts in IFS Cycle 43r1 results in forecast fields that reveal more detailed features and fit more snugly along coastlines. This is illustrated by these forecasts of daily mean sea-surface temperature for 18 November 2016, initialised at 00 UTC on the same day, using (a) the previous model version and (b) the new model version.

Other changes

Cycle 43r1 includes changes in the use of observations, data assimilation and in modelling, based on the results of research carried out at the Centre.

In data assimilation, for example, the method used to perturb the sea-surface temperature in the Ensemble of Data Assimilations (EDA) has been improved, and a higher-resolution EDA-based estimate of background errors (from TL159 to TL399 resolution) has been introduced. Furthermore, in the high-resolution assimilation, a weak-constraint method has been activated in the stratosphere (above 40 hPa). In terms of observations, 43r1 includes a new slant-path radiative transfer for all clear-sky sounder radiances used when interpolating model fields to observation locations. It also includes updated observation error covariance matrices and a change in the ozone anchor channels for IASI (Infrared Atmospheric Sounding Interferometer) and CrIS (Cross-track Infrared Sounder), obtained through a better treatment of observation uncertainty, and a new aerosol detection scheme for IASI, CrIS and AIRS (Atmospheric Infrared Sounder).

In modelling, 43r1 includes changes in boundary layer cloud for marine stratocumulus, and the use of a new ozone climatology. The land surface coupling coefficients for forest tiles have been modified to reduce night-time 2-metre temperature errors and improve the diurnal cycle. To improve the interactions between turbulent mixing (vertical diffusion), shallow convection and cloud parametrizations relevant to boundary layer cloud, changes have been introduced to the mass flux limiter, the up-draught momentum and the environment for shallow convection. These changes lead to increased cloud cover in the maritime subtropical stratocumulus decks, reducing forecast errors. The stochastic model error scheme SPPT (Stochastically Perturbed Parameterized Tendencies), which is active in both the EDA and the ENS perturbed members, has been revised, with the introduction of tendency mass conservation constraints.

New parameters

There are five new cloud and temperature diagnostic parameters in IFS Cycle 43r1 and improvements to others, as requested by users. The new parameters are (in brackets: grib identifier, short name and units):

- Ceiling: cloud base height relative to the ground (260109, ceil, m)
- Height of convective cloud top (228046, hcct, m)
- Height of zero degree wet bulb temperature (228047, hwbt0, m)
- Height of one degree wet bulb temperature (228048, hwbt1, m)
- Direct solar radiation, incident on a plane perpendicular to the sun's direction (47, dsrp, J/m^{-2})

Furthermore, eight new wave model output fields are generated:

- The magnitude and direction of the wave energy flux that is responsible for the impact of the waves on coastlines and offshore structures;
- Significant wave height of all waves in six different period ranges to help with the detection of low-frequency wave energy (Figure 3).

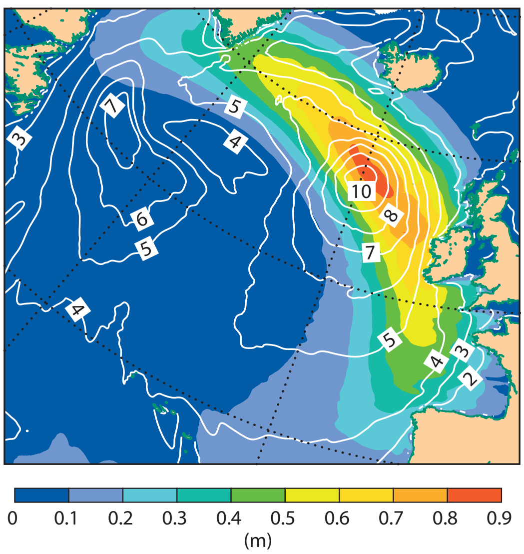

Figure 3 Seven-and-a-half-day (180-hour) forecast for significant wave height for all waves (contours) and for one of the new parameters, the significant wave height for all waves with periods between 21 and 25 seconds (shading), initialised at 00 UTC on 2 December 2016 . Even though the highest significant wave heights are still confined to the storm location, in the Atlantic south of Iceland, long waves from that storm, as depicted by this new parameter, are already affecting coastlines from Iberia to South Greenland.

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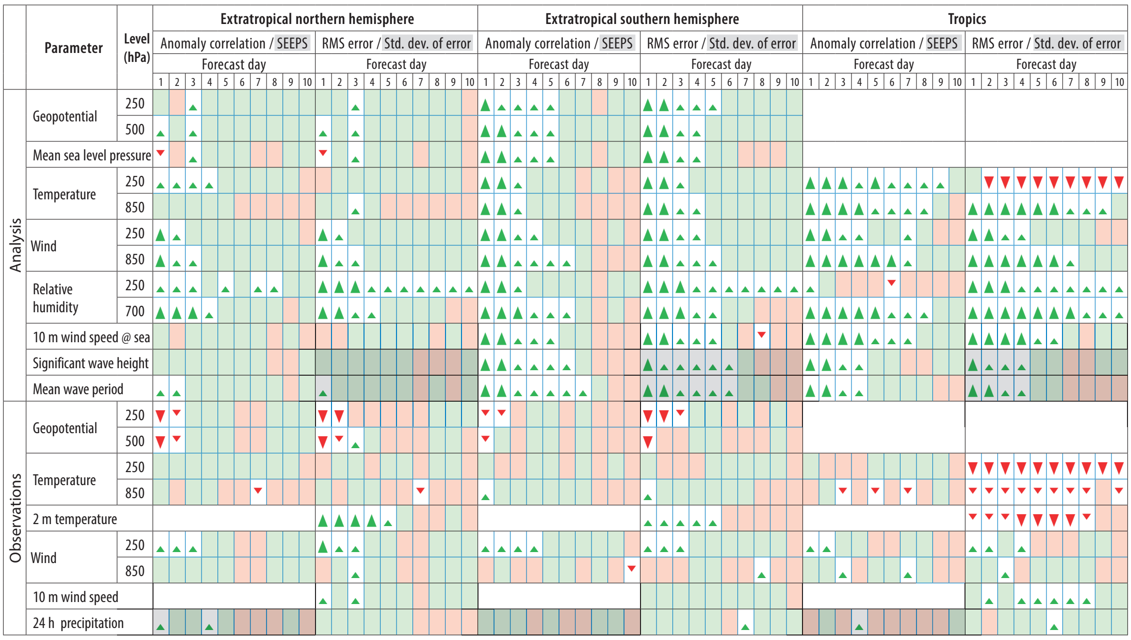
Better forecasts

Comparison of scores with the previous operational cycle 41r2 indicates that, for upper air fields, the new model cycle provides improved high-resolution forecasts (HRES) and ensemble forecasts throughout the troposphere and lower stratosphere (Figure 4). In the extratropics, error reductions of the order of 0.5-1% are found for most upper-air parameters and levels.

HRES 43r1 scorecard



ENS 43r1 scorecard

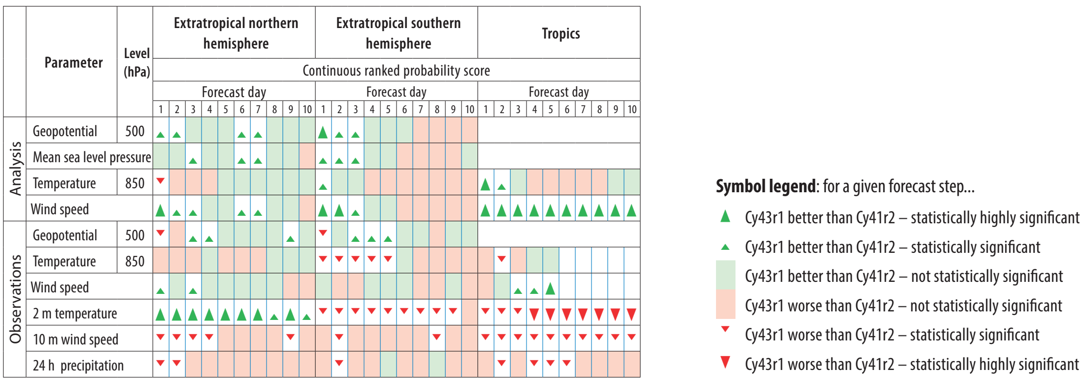


Figure 4 Scorecards for Cycle 43r1 HRES and ENS versus Cycle 41r2, verified by the respective analyses and observations at 00 and 12 UTC, for 764 forecast runs in the period 2 November 2015 to 21 November 2016 in the case of HRES and 118 forecast runs in the period 11 August to 21 November 2016 in the case of ENS. A more detailed scorecard can be found at *https://software.ecmwf.int/wiki/display/FCST/IFS+Cycle+43r1+scorecard*.

Improvements are most consistently seen in verification against the model analysis. In the tropics, there is a small degradation (both against analysis and observations) of temperature near the tropopause in terms of root-mean-square error (RMSE) but not in terms of anomaly correlation. This is due to a slight cooling caused by a modification in the treatment of cloud effects in the vertical diffusion scheme, which overall leads to improved cloud cover. While there is a consistent gain for upper-air parameters on the hemispheric scale, some continental-scale areas, such as North America and East Asia, show statistically significant improvements only at some levels and for some parameters.

Increases in upper-air skill of the ENS are generally similar to the single high-resolution forecast, with a substantial gain for mean sea level pressure. The improvement in the primary headline score for the ENS is small: a gain of about 0.5 hours in the skilful range of ensemble forecasts of 850 hPa temperature in the extratropical northern hemisphere, defined as the lead time at which the Continuous Ranked Probability Skill Score drops below 25%. The spread-error relationship is generally improved, partly due to reduced error and partly due to increased spread. For some parameters this improvement is quite significant, such as 850 hPa wind speed in the tropics, where under-dispersion is reduced by about 20% in the medium range.

In terms of weather parameters and waves, IFS Cycle 43r1 yields consistent gains in forecast performance in the tropics and extratropics for total cloud cover, mostly due to a reduction of the negative bias in low cloud cover. Changes in precipitation over land areas are small and overall neutral. In the HRES, the increase in forecast skill for 2-metre temperature is most pronounced in the short and medium range, where it amounts to a reduction of about 1% in RMSE in the northern hemisphere extratropics, and of up to 2% over some land areas, such as Europe and North America. In the tropics there is an increase of 0.5–1% in the RMSE for 2-metre temperature, connected to a slight increase of the overall cold bias at low latitudes. In the ENS there is a significant improvement in 2-metre temperature amounting to a 3% reduction in the Continuous Ranked Probability Score (CRPS) in Europe. Ten-metre wind speed shows error reductions of 0.5–1% over the ocean, leading to improvements in significant wave height and mean wave period, especially in the tropics and the southern hemisphere. Over land areas, changes in 10-metre wind speed forecast skill are generally neutral to slightly positive.

For the monthly forecast range, results indicate a modest positive effect on skill scores although the differences are not statistically significant. There is a substantial improvement in the skill scores for the Madden-Julian Oscillation, corresponding to a gain in lead time of 0.5–1 day at a forecast range of 4 weeks. The MJO spread is increased, bringing it closer to the RMSE. Verification of precipitation against analysis shows some degradation in the tropics, which is not statistically significant, and a reduction of precipitation biases in the northwest Pacific.

Conclusion

IFS Cycle 43r1 is the first upgrade since the Centre adopted a new Strategy for 2016–2025, and it reflects the direction of travel defined in the Strategy in a number of ways. First, the interactive sea-ice model introduced in IFS Cycle 43r1 is an example of the move towards Earth system modelling which is central to the Strategy. The aim is to represent the interactions between as many Earth system components as required, at the necessary level of complexity, to achieve the Centre's strategic goals. Second, both the sea-ice change and the higher ocean resolution have been implemented for ensemble forecasts, reflecting the Strategy's emphasis on ensemble-based analyses and predictions that describe the range of possible scenarios and their likelihood of occurrence. Finally, the Strategy sets ambitious goals for forecast skill, including the ability to predict large-scale patterns and regime transitions up to four weeks ahead and to make skilful predictions of high-impact weather up to two weeks ahead. The ability to evolve sea ice in the forecasts and the improvements in forecast quality brought by IFS Cycle 43r1 are small first steps towards achieving these goals.

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