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METEOROLOGY

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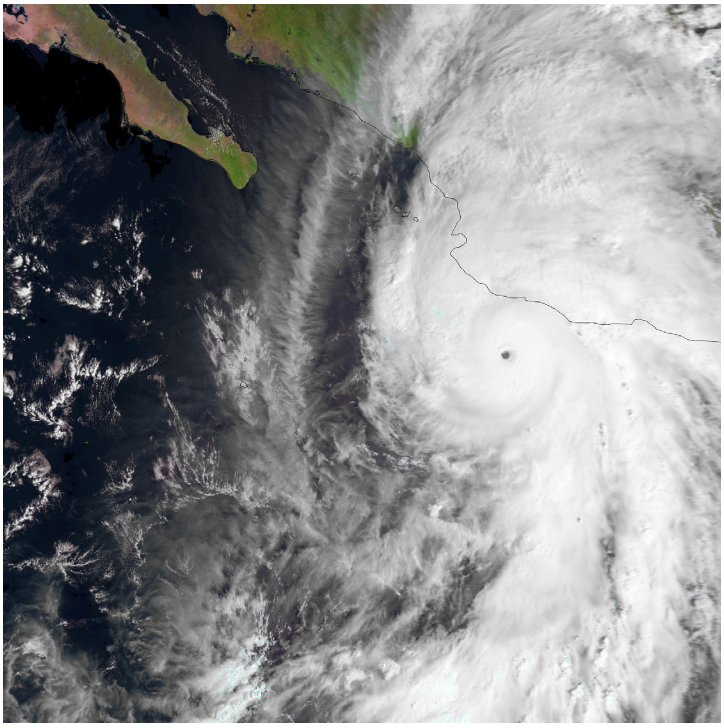

Hurricane Patricia off the coast of Mexico on 23 October 2015 (© 2015 EUMETSAT)

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IFS Cycle 43r3 brings model and assimilation updates

Roberto Buizza, Peter Bechtold, Massimo Bonavita, Niels Bormann, Alessio Bozzo, Thomas Haiden, Robin Hogan, Elias Holm, Gabor Radnoti, David Richardson, Michael Sleigh

On 11 July 2017, ECMWF implemented a substantial upgrade of its Integrated Forecasting System. IFS Cycle 43r3 includes 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 upgrade has had a broadly positive impact on forecast skill in medium-range and monthly forecasts. It follows the implementation of IFS Cycle 43r1 in November 2016, which for the first time included an interactive sea-ice model in the medium-range/monthly ensemble (*Buizza et al.*, 2017). Cycle 43r3 brings major changes in many areas, including:

- **In assimilation:** improved humidity background error variances directly from the Ensemble of Data Assimilations (EDA), like for all other variables; revised wavelet filtering of background error variances and revised quality control of dropsonde wind observations in the data assimilation to improve tropical cyclone structures
- **In the use of observations:** increased use of microwave humidity sounding data by adding new sensors; harmonised data usage over land and sea ice for microwave observations; improved screening of infrared observations for anomalously high atmospheric concentrations of hydrogen cyanide from wildfires; improved quality control for radio occultation observations and radiosonde data
- **In the model:** a new, more efficient radiation scheme with reduced noise and a more accurate longwave radiation transfer calculation; a new aerosol climatology including dependence on relative humidity, derived from data provided by the Copernicus Atmosphere Monitoring Service (CAMS); increased super-cooled liquid water at colder temperatures from the convection scheme; visibility calculation changed to use the new aerosol climatology
- **In software infrastructure:** new version control and software management tools; changes to enable single-precision experiments for all applications.

Expected impacts

A comparison of parallel runs of the previous operational cycle (43r1) and the new cycle (43r3) indicates in general a positive impact. As a result of the changes in data assimilation and in the way dropsonde observations are handled, analyses are expected to improve, especially in the case of tropical cyclones.

Results for both the high-resolution forecast (HRES) and the medium-range/monthly ensemble (ENS) indicate a positive impact, with many of the scores over the northern and southern hemispheres (NH, SH) and Europe indicating statistically significant improvements. Improvements are larger in summer than in winter. Changes to the deep convection scheme have improved the temperature gradient between the extratropics and the tropics. Significant improvements are found for temperature and vector wind throughout the extratropical troposphere. In the tropics, there is some deterioration in temperature and humidity at certain vertical levels associated with the changes to the deep convection scheme.

Considering the HRES, statistically significant improvements at the 95% level have been detected up to about forecast day 5 when forecasts are verified against the analysis. When forecasts are verified against observations, the positive impact of 43r3 is also evident. Surface parameters show partially statistically significant improvements both in the tropics and extratropics (2 m humidity, 10 m wind speed, total cloud cover, precipitation), except for 2 m temperature, which shows neutral results. Over the ocean, statistically significant improvements are seen for verification against the analysis for 10 m wind speed, significant wave height and mean wave period.

Results for ENS indicate mainly a positive impact similar to HRES both for upper-air and surface variables for the NH, SH, and Europe when verified against the analysis. In the tropics, there is some deterioration in upper tropospheric wind speed and lower tropospheric temperature associated with reduced spread. There is also some slight deterioration in tropical 2 m temperature and precipitation scores.

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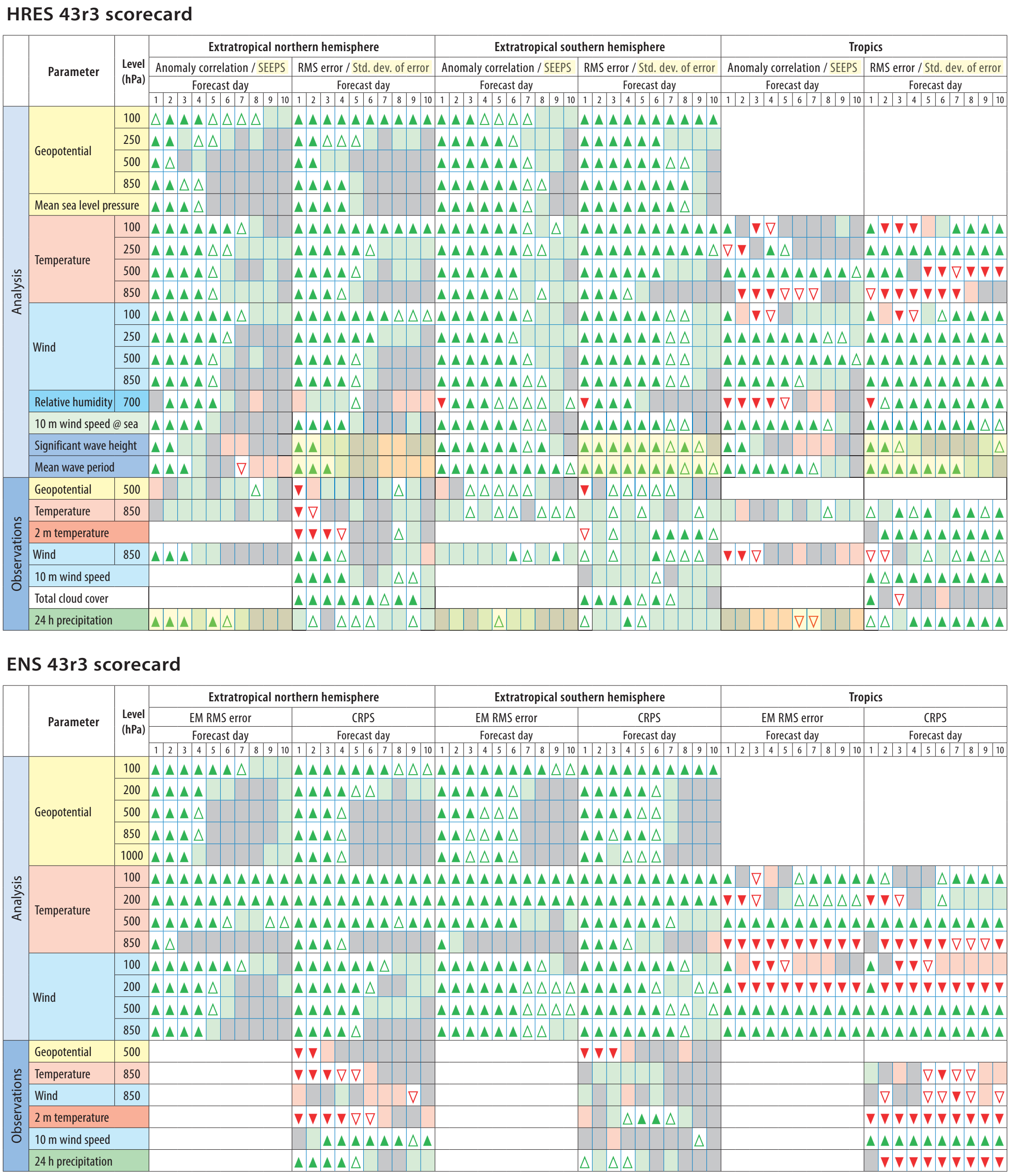
Changes in the tropical cyclone analysis are notable, with the cyclone structure defined in a better way. At forecast day 1 there is a marginally significant improvement in position error; the improvement is undetectable thereafter. Tropical cyclone intensity (as measured by central pressure) is slightly reduced from day 2 onwards: for lead times beyond four days this has a beneficial effect since it reduces the existing bias in tropical cyclone central pressure in such forecasts.

Figure 1 shows the HRES scorecard of Cycle 43r3 versus Cycle 43r1, based on experiments covering 740 forecasts from June 2016 to June 2017. It also shows the corresponding ENS scorecard for medium-range/monthly forecasts up to forecast day 15, based on 170 cases.



Symbol legend: for a given forecast step...

- ▲ 43r3 better than 43r1 statistically significant with 99.7% confidence
- △ 43r3 better than 43r1 statistically significant with 95% confidence
- 43r3 better than 43r1 statistically significant with 68% confidence
- difference between 43r3 and 43r1 statistically insignificant
- 43r3 worse than 43r1 statistically significant with 68% confidence
- ▽ 43r3 worse than 43r1 statistically significant with 95% confidence
- ▼ 43r3 worse than 43r1 statistically significant with 99.7% confidence

Figure 1 Scorecards for Cycle 43r3 HRES and ENS versus Cycle 43r1, verified by the respective analyses and observations at 00 and 12 UTC, based on 740 HRES forecast runs and 170 ENS forecast runs in the period June 2016 to June 2017.

Data assimilation

In Cycle 43r3 two significant upgrades in the 4-dimensional variational assimilation configuration (4DVAR) have been implemented. The first involves using background humidity error estimates sampled from the Ensemble of Data Assimilations (EDA) in the 4DVAR analyses (both in the high-resolution version and in the EDA itself) instead of the previously used statistical model. This change makes the treatment of humidity background errors consistent with the rest of the control vector and makes the error estimates more flow dependent. The humidity error change has led to improvements in the forecast fit to humidity-sensitive observations and to reductions in wind vector forecast errors. In addition, the updated climatological background error statistics (B matrix) improve the forecast fit to stratospheric satellite data.

The second upgrade involves the way observations are assimilated and the weight given to dropsonde observations near the centre of tropical cyclones. Previously the analysis of tropical cyclones occasionally showed unrealistic features (e.g. double centres, elongated cores). These problems were tracked to unrealistic observation error values assigned to dropsonde observations, and to the increase in the resolution of the EDA background errors adopted in Cycle 43r1. The upgrade has improved the tropical cyclone initialisation by introducing an adaptive observation error model for dropsonde measurements and a smoother filtering of the background error. The latter was achieved by spectrally truncating the errors to TL159 instead of TL399 and applying a new wavelet instead of spectral signal-to-noise filter. A positive side effect of this change is a reduction of around 5% in the time spent in the critical path of 4DVAR. Figure 2 shows the impact of these changes on the analysis of tropical cyclone Patricia (23 October 2015, Eastern Pacific).

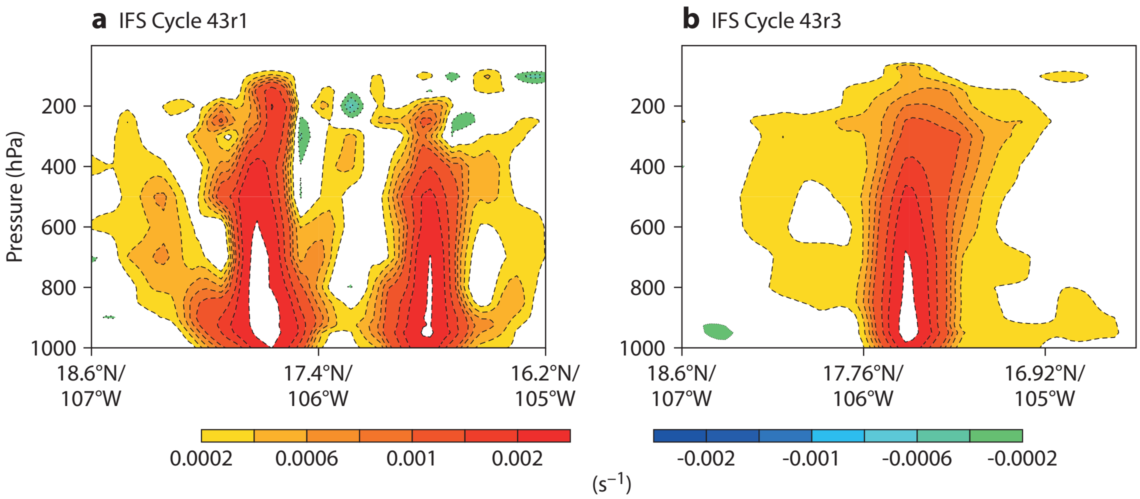


Figure 2 Tropical cyclone high-resolution analysis of relative vorticity (cross section) for 12 UTC on 23 October 2015 produced using (a) the previous IFS cycle, 43r1, and (b) IFS Cycle 43r3. In IFS Cycle 43r3, there is a more cautious use of dropsonde wind observations by means of adaptive observation error and smoother filtering of the EDA background error variances.

Observations

Cycle 43r3 makes greater use of microwave sounding data by adding new sensors and improving the usage of existing data. The Global Precipitation Measurement Microwave Imager (GMI) humidity-sounding channels have been activated along with SAPHIR (Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions), a humidity sounder with frequent tropical coverage (Figure 3). Microwave Humidity Sounder (MHS) observation errors have been reduced over land, and MHS channel 4 is now used over snow-covered land surfaces. Additional Advanced Technology Microwave Sounder (ATMS) humidity and temperature sounding channels are being used over sea ice and cold seas. The Micro-Wave Humidity Sounder 2 (MWHS-2) 118 GHz channels, which are sensitive to temperature and cloud, have been added over land surfaces. There have also been passive updates to prepare for the all-sky assimilation of the Advanced Microwave Sounding Unit-A (AMSU-A), and possible future use of the Micro-Wave Radiation Imager (MWRI). These changes increase the existing impact of all-sky humidity observations. The largest improvements are seen for vector wind and of course humidity itself. Anomalously high atmospheric concentrations of hydrogen cyanide (HCN) from wildfires are now detected dynamically and

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infrared observations are only excluded when safe thresholds are exceeded. This replaces the previous approach of constantly blacklisting all potentially HCN-affected channels. The first-guess check for radio occultation observations has been tightened. The radiosonde vertical consistency check has been relaxed and observation errors for temperature and humidity now depend on radiosonde type.

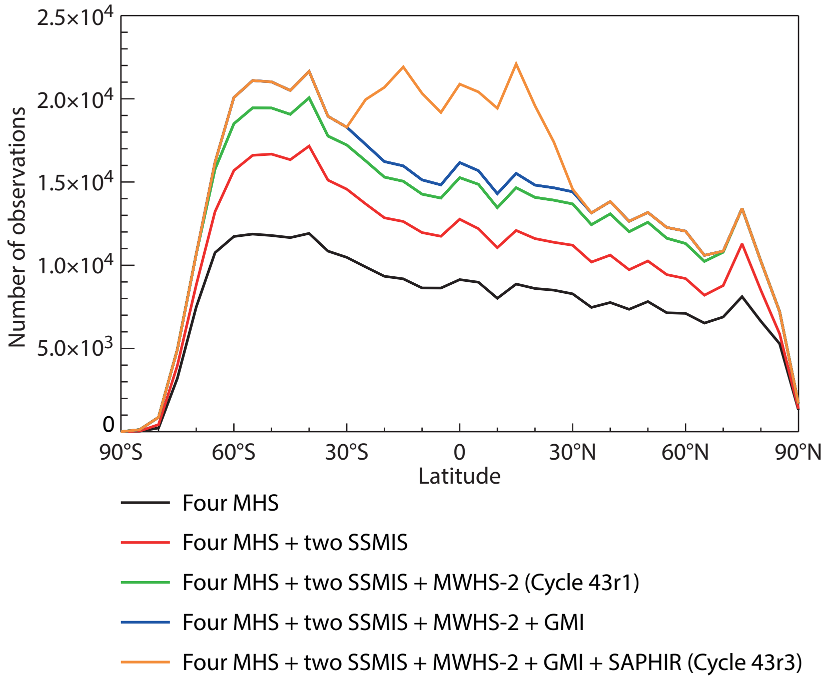

Figure 3 Number of assimilated all-sky microwave humidity observations around 183.3 ± 3 GHz as a function of latitude for 31 August 2016. The number of observations used in Cycle 43r1 is shown in green, with contributions from four microwave humidity sounders (MHS), two Special Sensor Microwave Imager/Sounders (SSMIS) and one Micro-Wave Humidity Sounder 2 (MWHS-2) instrument. In Cycle 43r3, observations from the Global Precipitation Measurement Microwave Imager (GMI) and the Sounder for Atmospheric Profiling of Humidity in the Inter-tropical Regions (SAPHIR) have been added.

Convection scheme changes

Several improvements in the treatment of microphysical processes in the convection scheme affect the profile of latent heat release. In particular:

- Glaciation of cloud water now occurs in the temperature interval from 0 to –38°C rather than 0 to –23°C, with freezing rain treated directly in the updraft scheme.
- Snow now melts to form rain when wet-bulb rather than dry-bulb temperature is 0°C.
- Not just cloud condensate but also rain and snow are now detrained to the cloud scheme.

Temperature and geopotential-height biases at the melting level and in the upper troposphere have been strongly reduced. Tropospheric winds in summer, notably subtropical jets, have strongly improved. A measureable improvement in forecast skill is evident in the northern-hemisphere summer. Elsewhere the impact is mostly neutral.

New radiation scheme

The radiation scheme has been completely recoded to be much more flexible. The four primary components (gas optics, cloud optics, aerosol optics and solver) can now be changed independently of each other, and it is possible to choose between several new solvers that include longwave scattering and three-dimensional radiative effects. The first operational implementation in 43r3 is similar to the old radiation scheme, but there are already three improvements. First, the new scheme is 30–35% faster than the old one. Second, thanks to a more exact solution of the longwave equations, extreme values in the temperature profile are reduced, which means that the tropopause is now warmer and the stratopause is now cooler in the model, reducing the existing bias in both locations (Figure 4). Third, the new McICA scheme to represent cloud structure is less noisy in partially cloudy situations, which leads to a small improvement in tropospheric forecast skill (smaller than that brought about by the changes to the convection scheme).

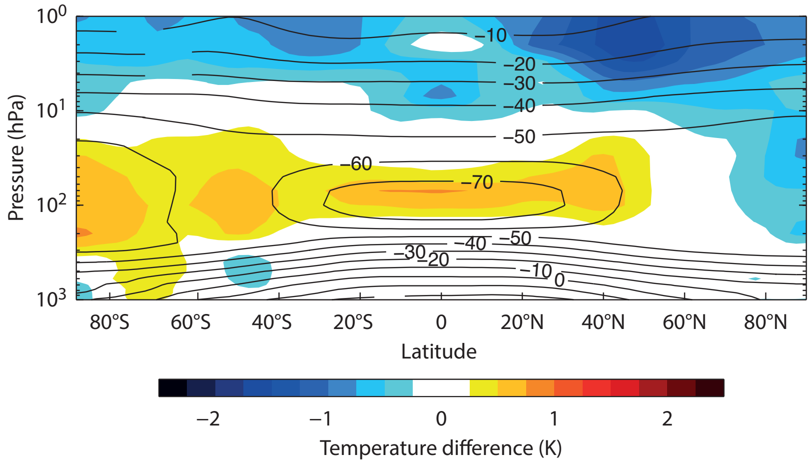

Figure 4 Difference in zonal-mean temperature between the new radiation scheme and the previous one (IFS Cycle 43r3 minus IFS Cycle 43r1 – shading) for a four-year coupled climate simulation. The contours show temperature in °C according to the climate simulation using IFS Cycle 43r3. The upgrade reduces the existing bias in the tropopause and the stratopause.

New aerosol climatology

In Cycle 43r3, the Tegen aerosol climatology, which was operational for 14 years, has been replaced with a new climatology derived from data provided by CAMS. This includes the rigorous computation of aerosol optical properties using revised refractive indices in each band of the entire longwave and shortwave spectrum. In addition, the humidification of hydrophilic aerosol is modelled by exploiting the dependence of optical properties on relative humidity. The new climatology leads to an improved representation of the Indian summer monsoon, which is currently too strong in the IFS (Figure 5). 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 current overestimate of rainfall over the west coast of India.

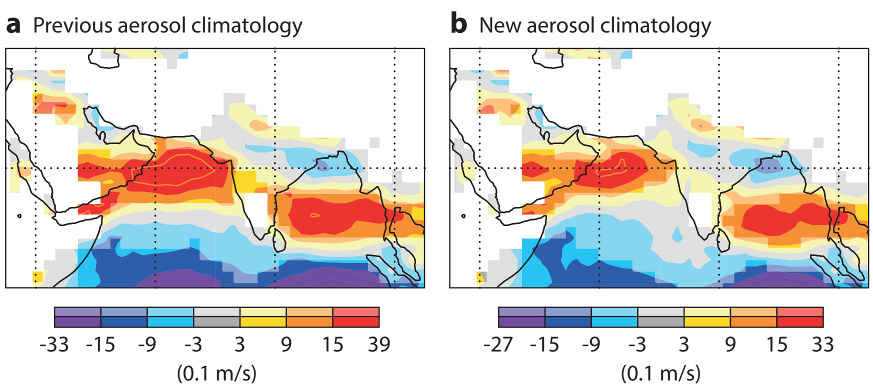

Figure 5 Bias in the day-5 forecast of 925 hPa zonal wind in the Indian monsoon region in summer (June–August) for (a) the previous IFS cycle, 43r1, and (b) IFS Cycle 43r3 with the new aerosol climatology. Saturated colours indicate areas where the signal is significant at the 95% confidence level.

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Software infrastructure

As part of the upgrade, IFS version control has been migrated from the Perforce version to Git, and the JIRA tool has been introduced for issue tracking and software management (see the separate article on these developments in this issue of the Newsletter). In addition, changes have been introduced to make it possible to perform single-precision experiments for all applications. Running parts of the IFS at single precision (with a 32-bit representation of real numbers) instead of double precision (a 64-bit representation of real numbers) has the potential to dramatically increase computational efficiency without compromising forecast quality. It could lead to more efficient experimentation and possibly even forecast production. This is an area of active research (*Váňa et al.*, 2016).

Summary

The ten-year Strategy adopted by ECMWF in 2016 includes two key scientific goals to help achieve improved medium-range forecast skill: a more accurate estimation of the initial state and the consistent representation of uncertainty associated with observations and the model; and a better representation of physical and chemical processes and of the interactions between different Earth system components. This IFS upgrade brings important advances in both areas. It enables the use of more observations and improves their assimilation; and it includes changes to the convection and radiation schemes and introduces a new aerosol climatology, thus bringing an improved representation of Earth system processes. Both developments have led to significant improvements in forecast skill. The upgrade also helps to pave the way for future progress by updating ECMWF's software infrastructure. This will notably facilitate further work on single precision, which is expected to make an important contribution to the Centre's Scalability Programme.

Further reading

Buizza, **R.**, **J.-R. Bidlot**, **M. Janousek**, **S. Keeley**, **K. Mogensen** & **D. Richardson**, 2017: New IFS cycle brings sea-ice coupling and higher ocean resolution, *ECMWF Newsletter* **No. 150**, 14–17.

Váňa, **F.**, **G. Carver**, **S. Lang**, **M. Leutbecher**, **D. Salmond**, **P. Düben** & **T. Palmer**, 2016: Single-precision IFS, *ECMWF Newsletter* **No. 148**, 20–23.

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