Known IFS forecasting issues

Please note that numbering/ordering does not indicate/imply any sort of priority. Recent entries/changes/updates are shown in green. Greyed out means no longer current, but these issues can be relevant when examining archived forecasts.

Any enquiries related to the content of this page should be emailed to servicedesk@ecmwf.int (mentioning the "Known IFS forecasting issues web page").

<table>
<thead>
<tr>
<th>Topic / title</th>
<th>Description</th>
<th>Related activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>2m Temperature</td>
<td>In common with all models, 2m temperature forecasts from the IFS tend to have much larger errors, on average, during low level inversion situations, which are particularly common at high latitudes in winter. The basic physical explanation is that a set change in atmospheric energy content has a much larger impact on screen temperature in inversion situations than in unstable situations, because the energy change is commuted through a much smaller depth of the atmosphere (e.g. metres rather than kilometres). The lower the inversion, the larger is the potential error. There is also sensitivity here to the method we use to interpolate between air temperature at the lowest model level (~10m) and skin temperature (2m temperature is a diagnostic, not direct model output).</td>
<td>New reporting practices for radiosonde data (&quot;BUFR&quot; messages), slowly being introduced around the world, may alleviate this problem slightly, by providing model analyses with a much more detailed representation of the near surface layers. In regions with snow cover, where issues are often most apparent, a change in IFS formulation, from using a single-layer to a multi-layer snow scheme (potentially late in 2022), will also help somewhat (see also item S5 below).</td>
</tr>
<tr>
<td></td>
<td>Due to the urban heat island effect not being represented, screen temperatures in large urban areas, particularly cities, are commonly too low compared to observations. The problem can be accentuated in winter by snow cover.</td>
<td>'Urban tiles' to be introduced in land surface scheme in due course.</td>
</tr>
<tr>
<td></td>
<td>As a consequence of the radiation grid being larger than the model grid (due to computational constraints) night-time radiative cooling over land near to the coast is often too rapid. This is because cooling progresses according to T^4, and at near-coast points T is approximately the average temperature of the land and (warmer) ocean. AS a result screen temperatures drop too much - related errors can sometimes exceed 10C. The problem is enhanced (i) when there is snow cover, (ii) at high latitudes, and (iii) where coasts have a convex shape (land-relative).</td>
<td>Improvements due to radiation code 'fixes' were introduced with cycle 41R2 in March 2016. In example cases the impact of these changes has been very positive. More substantial radiation code changes are likely in the longer term.</td>
</tr>
<tr>
<td></td>
<td>In addition to the normal problems of representing screen temperatures in complex topography in current-generation global models, the user should be aware that the method by which screen temperatures on Meteograms are generated from model screen temperatures assumes a standard lapse rate (6.5°C drop per km increase in altitude), and so if the difference in height between the site chosen, and the nearest model gridpoint (as shown in the ENSgram title) is large, the scope for large errors /biases increases. This is especially true in winter-time when inversions are more common: by definition an inversion implies a temperature increase with height, not a decrease, so the temperature correction applied could even be in the wrong direction. This issue is compounded by 2m Temperature issue T1 above.</td>
<td>Resolution upgrade in March 2016 (41R2) helped. Users can mitigate the impacts, in certain circumstances, by judicious selection of representative gridpoints. To help, guidelines on how meteogram data relates to model gridpoint data (with the new MIR interpolation scheme) have been comprehensively updated in the Forecast User Guide - see here.</td>
</tr>
</tbody>
</table>
There is a semi-permanent winter-time 'cold spot' over parts of central/eastern China. This can be most apparent in products that intrinsically display 2m temperature output in some 'anomaly' form - such as monthly forecast anomalies, seasonal forecast anomalies, and in the shorter ranges EFi and SOT. This is caused by a number of overlapping issues, whose (relative) importance can vary from day to day and from case to case:

a) Sometimes the cold spot may not correctly reflect the IFS output in the sense that 2m temperatures are not always "below normal" in this area when they are shown to be. In such cases the cold spot can owe its existence to incompatibilities between the current forecasting system, and ERA-Interim (ERA-I). ERA-I-based re-analyses are used to start the re-forecasts which form the 'model climatology' against which current forecasts are compared. So whilst these re-forecasts are rightly performed with the latest model version, they also inherit, as a starting point, auxiliary data such as snowfall from ERA-I, which feeds the ERA-I 'offline fields'. In turn this offline snow depth inevitably derives, in part, from what the ERA-I model puts on the ground in the way of snowfall, and this model's climatology is such that there is less snowfall in this area, on average, than in the current HRES. So HRES and other IFS components are inclined to have deeper snow cover in their analyses through the winter than the re-forecasts have in theirs, which encourages the development of 2m temperatures that are similarly lower - i.e the 'cold spot' anomalies.

b) Sometimes the 2m temperature output from the IFS is genuinely and continually too cold, by 10C or more. In such instances the cause can be insufficient melting, on the ground, in the autumn, of sleet/snow that fell in the model (see items S2 and S3 below). The snow remains on the ground, the air cools as a result, an inversion arises, more insolation is reflected out to space, and so on. This unwanted feedback loop is difficult to interrupt, in this part of the world, with mild air incursions, and the problem can persist for weeks or even months (as in late 2018).

c) The IFS does not account for the drifting of snow on the ground. Snow that drifts will of course be redistributed, and will also sublimate more readily. Both can act to reduce snow depths in reality in a way that is not captured in the IFS, and real 2m temperature errors again result via the feedback loop referred to in (b).

d) Issues (a), (b) and (c) are compounded by a historical dearth of snow depth observations in this area which might have helped bring things back on track, and also by an IFS snow analysis scheme 'feature' that anyway excludes all observations above 1500m (the said area is around 4000m). NOAA's daily northern hemisphere snow cover analysis, that does have complete spatial coverage, and that the IFS does utilise, is also discounted in this particular region because of the altitude. The 1500m cut-off can help avoid problems in complex terrain, though could be improved by using instead a measure of sub-grid orography to incorporate data over high level plateaus.

Since June 2019 (with cycle 46r1) the new re-analysis ERA-5 has been driving the re-forecasts: this helps as it is much more compatible with the current model. Longer term, increases in African observational coverage should also (1) improve the actual forecast, and (2) facilitate objective verification.

A partial fix has been created, by changing the thermal conductivity parameter for wet tiles. This will reduce the number of instances by almost half. It was introduced in 2019 (46r1). Work continues.
| T9. Temperature errors related to vegetative | In quiescent conditions in springtime in particular, but perhaps also in autumn, forecast daytime temperatures can repeatedly be far too low in some extra-tropical regions. Errors of 5-10°C have been relatively commonplace in short range forecasts in such conditions in recent years (e.g. in SW Russia). Initial investigations suggest that the error is because the IFS has too much leaf coverage (strictly the leaf area index or LAI), compared to reality/climatology, in the transition seasons. Although LAI in the IFS is nominally based on climatology, it is actually held artificially high during these seasons, because to do otherwise would lead to other larger errors, on average, for complex reasons that are not fully understood. With large LAI, as in the IFS when these errors occur, more insolation goes into latent heat at the surface (evapotranspiration), whilst in reality more should be available for sensible heating to help increase 2m temperature. There is also a positive feedback from the anomalous evaporation, which increases cloud cover too much, which in turn reflects back insolation and reduces solar heating. Experiments show that in these particular situations correcting the LAI does correct the 2m temperature, even though in general it gives a degradation in scores. Investigations continue. |
| Precipitation | **P1. Marine convection propulsion**
In reality shower cells have a finite lifetime, so precipitation associated moves with the showers, as one can see on radar. In the IFS showers are instantaneous (as they are parametrised) and the related precipitation does not propagate. So showers triggered over the sea do not generally move inland in the model as they should. This can lead to under-prediction errors of several mm in inland locations, 10mm or more in extremis. The degree to which the error extends inland depends on the windspeed at the steering level for showers. For stronger winds the errors extend further inland. For snow showers the errors can be worse still, compounded by the relatively slow fall speed of snowflakes (up to say one tenth of that of raindrops). So a snowflake starting its descent at the coast might end up on the ground 100km inland, if winds are strong, whereas a raindrop in equivalent summer conditions might only propagate 20km before reaching the ground. Snow issue S1 relates. 2017 IFS changes (43r3) included detrainment of some hydrometeors from convection into large scale precipitation, bringing a small positive impact as those hydrometeors now drift with the wind. The new "moist physics", introduced in October 2021, changed many aspects of precipitation output (see [here](#)), but has not materially affected this issue. |
| **P2. Underesimation of orographic enhancement of precipitation extremes**
As a consequence of topographical barriers being too low, in general (due to resolution), both the orographic enhancement of precipitation and the rain shadow effect tend to be underestimated in the IFS (more so in ENS than HRES, and more so in ENS after 10 days when resolution changes). Resolution upgrade in March 2016 (41r2) has helped. Integrated moisture flux diagnostics introduced in June 2018 (45r1), and EFI and SOT fields for those introduced in June 2019 (46r1), may also provide some assistance for predicting orographic rainfall. |
| **P3. Underesimation of convective precipitation extremes**
As a consequence of resolution, and the related parametrisation of convection, localised extreme values in precipitation totals will be systematically "underestimated" in IFS output. Differences equal to about one order of magnitude are possible. However this is not as bad as it seems, because when verified over areas that are the same size as the effective model gridbox size the agreement is generally much better. Note also that one should expect point maxima to be systematically higher in HRES than in ENS, due to resolution differences. Resolution upgrade in Mar 2016 helped a bit. New ECMWF precipitation downscaling initiative incorporates the estimation of sub-grid variability, and verifies very well, delivering much better predictions of rainfall at points, including extremes. Related 'point rainfall' products became available in April 2019 in ecCharts (documented [here](#)). See also P8. One impact of the new "moist physics", introduced in October 2021, has been to increase localised convective rainfall maxima at the gridscale (see [here](#)). Users should still expect maximum rain gauge values to be well in excess of a raw model forecast however, if sub-grid variability is large. |
| **P4. Tropical rainfall extremes greatest on day 1**
If one examines the distribution, in forecasts, of daily rainfall totals for locations in the tropics, the (we) tails tend to be longer for very short lead times (e.g T-0 to T+24), implying that ENS has a greater propensity to generate extreme rainfall in short range forecasts than they do in medium range forecasts. For example the 99th percentile of daily rainfall at some locations at day 1 is twice what it is at day 3. This would appear to be a 'spin down' issue, of sorts, related to the handling of convection. Formulation of the EFI and SOT is such that they should intrinsically account for this (though note Miscellaneous issue M1 below), so the problem arises for the user particularly when referencing the direct model output. ECMWF examined this issue closely during summer 2017. The causes are complex. The issues are still present in the 46r1 M-Climate (that uses ERAS). Further investigations in 2020 found a net spin down of average precipitation in the ENS, on day 1, globally, of about 20% in the first 12h, whilst HRES and Control did not exhibit any such spin down behaviour. These characteristics were much the same in cycles 46r1 (introduced 2019) and 47r1 (introduced 2020). |
| **P5. Extreme rainfall at certain gridpoint s ("rain bombs")**
At particular gridpoints, that lie in areas of complex topography, IFS forecasts (notably HRES) can occasionally generate extreme localised precipitation totals in a matter of hours, say well over 100mm, when at neighbouring locations the amounts are far less. These extremes are incorrect: the error occurs in convective situations with light winds. Only a small number of gridpoints around the world are affected - mainly these lie in the following areas: southern China, parts of Eastern Africa, Papua New Guinea, along the Andes, southern Mexico. The cause is understood though is too involved to describe in detail here; in short it relates to a weakness in the semi-Lagrangian scheme (part of the model numerics). Tests have shown that the error will go away when the grid structure and model resolution are changed with the next cycle. This issue was resolved with the introduction of cycle 41r2 in March 2016 (however the problem is still present in ERAS output, because although that is also based on 41r2, it does not use the octahedral grid). |
**P6. Large-scale precipita
tion gradient**
smatch the land-
sea mask

In some large-scale "warm rain" situations water bodies - sea and lake - can
sometimes experience much more precipitation than adjacent landmasses in the IFS.
This is unrealistic. The cause is complicated, relating to pragmatic historical tuning of
cloud physics parameters, which have had some relationships with the underlying
land-sea mask. In effect precipitation rains out much more readily over water bodies.
Even small regions, such as the IJsselmeer in the Netherlands, or Lake Vanern in
southern Sweden can exhibit these problems. In extremis rainfall rates can vary,
unrealistically, by an order of magnitude across the land-water boundary (e.g. 0.2
versus 2.4mm/hr). Very warm moist air seems to be most prone to such issues.

**A complex raft of modifications to the cloud physics schemes, which include reverting some earlier
tuning, has delivered clearcut improvements in tests. Implemented in early June 2018 (45r1).**

**P7. Anomalou
s convecti
ve rings
and squall
lines in
tropical rainfall**

Animating HRES total precipitation rate in the Tropics one can detect, almost every
day, instance(s) where a burst of localised high rates spawns an annulus, of
increasing radius, of more modest rates, like a ripple from a stone in a pond. The
initial burst tends to be large scale rain, effectively resolved convection, whilst the
rings themselves are parametrised convection. Similar features do appear in nature,
but the amplitude in the IFS is too large. The cause may be an over-active convective
outbreak at the outset that triggers an over active adjacent downburst in response,
which itself propagates outwards as a gravity wave, and which in turn helps trigger the
convection scheme preferentially at its leading edge, where there is more forced
ascent. Evidence has mainly been seen over tropical oceans, but also in the Sahel
region of Africa. Spurious squall lines can also be created in IFS forecasts in a similar
way (e.g. over Africa). These may propagate in a direction that is opposite to the
propagation direction ordinarily observed when squall lines do occur in a given region.

Introduction of the new moist physics package, to October 2021, has alleviated some instances of
this type. Squall lines can look much more realistic than hitherto (see here).

**P8. Biases when forecasti
ng rainfall at
points - 'drizzle
problem'**

The IFS predicts gridbox average rainfall. Users often compare such gridbox forecasts
with rainfall measured at points. Verification in this way reveals "biases", which are not
always true biases but instead representivity issues, due to sub-grid variability. These
apparent biases consist of over-prediction of small totals, and under-prediction of
large totals, and are most apparent for parametrised convective precipitation which
has greater sub-grid variability than large scale precipitation. Some users have referred
to apparent over-prediction of small totals as the "drizzle problem", which is somewhat
misleading if it relates to convective precipitation, which does not imply drizzle.

In 2018 focussed verification at ECMWF, using high density observations, has shown
that as well as the above representivity issue, in certain circumstances there can also
be IFS over-prediction on the gridscale.

New ECMWF precipitation downscaling initiative incorporates the estimation of sub-grid variability,
and also corrects for many weather-type-depandent gridscale biases. This verifies very well,
delivering much better predictions of rainfall at points. This includes alleviation of the so-called
"drizzle problem". The related "point rainfall" products became available in April 2019 in
eCharts, documented here. See also P3.

**P9. Validity of
very small
totals.**

Due to grib packing issues for total precipitation fields, and related discretization, very
small precipitation totals may not be accurately represented in ECMWF output.
Accumulation values <0.04mm, in the period up to day 10, including those computed
by subtraction, are unsafe; we recommend setting values below this threshold to zero.
At longer lead times an even higher threshold may be appropriate.

GRIB 3 may help.

**P10. Occasiona
l convecti
ve rainfall
in arid
regions under-predic
ded.**

Occasionally, particularly in areas and/or at times of year that are climatologically arid,
the IFS correctly predicts daytime convective activity - as represented by the ECMWF
lightning diagnostic - but zero rainfall at the surface. In such situations localised
rainfall, at sub-grid level, can sometimes be observed. Whilst the gridbox average
rainfall rate could not and will not capture localised sub-grid maxima, to be unbiased it needs to
be greater than zero in such situations. There are two main candidates to explain the
bias:

(i) the main cause is believed to be the dependence of the convective parametrization on
CAPE (convectively available potential energy). As CAPE can be relatively low in
these situations, the amount of precipitation produced from the convection scheme is
small, which subsequently evaporates before reaching the surface.

(ii) a second potential contributor could be the evaporation of the rain in the dry air
below cloud base. The evaporation is very dependent on the assumed drop size
distribution for the rain and subgrid relative humidity variations in the sub-cloud layer.
Larger drops in more humid air will penetrate further downwards before evaporating.

ECMWF's "point rainfall" post-processed output could in principle adjust for the bias, but in the
present formulation the model gridbox rainfall forecast acts as a multiplying factor, so zeros are
never altered.

The new moist physics package introduced in October 2021 has helped to address this issue. It
delivers rainfall more often in arid regions.

**Snow**

**S1. Snow
Drift in
convecti
ve situations**

When snow falls through cloud or beneath cloud it drifts with the wind. For large-scale
(dynamic) precipitation IFS physics accounts for this. For convective precipitation
however it does not; there is no drift, the precipitation arrives at the surface
instantaneously once the convection is diagnosed, in the place that it is diagnosed. As
a result snow arising from convective processes may be misplaced in the model (too
far upwind), and the errors will be larger if winds along the snowflake path are
stronger. Errors can be of order 100km. Precipitation issue P1 relates. The same
issues exist for rain, but given the faster fallspeed of raindrops relative to the IFS
model resolutions these errors are negligible. Clearly one also has to take account of
the melting level.

2017 IFS changes (43r3) included detrainment of some hydrometeors from convective into large
scale precipitation, bringing a small positive impact as those hydrometeors then drift with the wind.
<p>| S. | Snow on the ground takes too long to melt | In both ENS and HRES small amounts of snow on the ground tend to take too long to melt, even if the temperature of the overlying air is well above zero. This is because, for melting purposes, the snow that there is is assumed to be piled up high in one segment of a gridbox. For smaller nominal depths, the pile becomes higher, though at the same time covers a much smaller fraction of the box. The reason this is used is to improve the handling of screen temperature; by confining the snow to gridbox segments the impact on the temperature of that snow is reduced, and on average we find smaller errors and biases in 2m temperature as a result. The main downside is that snow cover pictures can look misleading, particularly at longer leads (when they can not of course be rectified by observational data). The cut-off above which snow is assumed to cover the full grid box is a 10cm depth - this is why a green hue used on standard snow depth charts on the web, which suggests to the eye the presence of some vegetation, disappears at 10cm. | One related coding bug was identified and removed during the winter 2017/18, which helped a bit, but the problem of correctly representing the physics remains. |
| S2. | Mixed rain/snow leads to snow accumulation | In marginal snow situations, when precipitation at the surface comprises both rain and snow, the snow component accumulates as lying snow. In the vast majority of cases this is wrong - it should melt instantaneously. This behaviour occurs because small snow depths within the model are assumed to be piled up into a small segment of a gridbox, and as such it is very difficult for them to melt quickly (as in Snow issue S2 above). | |
| S3. | Spuriou s snowfall in freezing rain situations | In certain winter situations, when snow descends through the atmosphere and melts to rain in a warm layer, before descending again through a cold (sub zero) layer, the model turns the precipitation back to snow far too readily. So surface precipitation in freezing rain situations commonly appears as snow, and that snow also accumulates on the ground. HOWEVER, it seems that where this precipitation is diagnosed as convective, this re-freezing problem does not exist. | Resolved with physics changes implemented in May 2015, though monitoring still required. |
| S4. | Multiple snow layers | The model assumes that all snow on the ground has the same density (though that density does vary - e.g. increasing with age). So layers of different density, which arise in the real world, are not catered for. This can impact on several things, such as total snow water content, and upward heat conductivity, which in turn has the potential to adversely affect 2m temperature. In addition, when new snow falls onto old, the change in snow depth is commonly less than would be expected, because the density assigned to the fresh snow depends in part on the density of the pre-existing lying snow, and so tends to be greater than it should. The magnitude of the error (in snow depth change) increases when the pre-existing snow is deeper and/or has a greater density. Example: if 10cm of new snow (ratio 12:1) fell onto 10cm of old lying snow (ratio 2.5), snow depth in the model would increase by only 3.5cm. | A 5-layer snow scheme is now under trial, with operational implementation anticipated for early 2023. |
| S5. | Analysed snow depths can oscillate between runs. | In certain winter scenarios - e.g. where deep snow is melting - the snow depth analysis can show much more snow at one of the main data times (e.g. 12UTC) than at the other (e.g. 00UTC). This can have a large detrimental impact on the 2m temperature forecast (compounded by issue S2). The cause is erratic reporting practice (in certain countries in particular) wherein zero depth reports may only be available at certain times of day. When they are not available the analysis scheme tends to interpolate between the available (non-zero) values, making both the spatial coverage and integrated snow volume across a region too large. | Improved reporting practices would address this issue. Assimilation-related solutions may also be possible, although creating and evolving different strategies for different countries is challenging and time consuming. |
| Tropical Cyclones | | | |
| TC1. | Tropical cyclone intensity | Resolution limits our ability to fully capture the depth of some TCs, errors can be over 50hPa in extremis. The problems are larger for smaller systems, with a smaller eye - Haiyan was one such example. Often minimum pressure in HRES will be lower than in all the ENS members, and likewise winds stronger than in all ENS members; this is because of the higher resolution of HRES. In such situations HRES guidance may be better, but not always. | With cycle 41R2 introduced in March 2016 came a resolution upgrade, and a substantial improvement to resolution used in the EDA. Key impacts were a marked reduction in positive depth bias in ENS analyses and forecasts, and more spread in ENS depth forecasts. |
| TC2. Relatively slow-moving TCs can deepen too much in HRES | There is no coupling with the ocean in HRES. So for relatively slow moving TCs, when fluxes and mixing might in reality lead to a reduction in SST, the SST will remain at an elevated level and this can give the TC extra impetus to deepen too much (provided other factors such as shear remain favourable). For fast moving TCs the affected ocean is left behind, and so the problem is less acute or non-existent. Whilst issue TC1 above generates errors in the opposite sense that might sometimes fortuitously cancel, there are nonetheless recorded cases where TCs have been over-deepened, by as much as 50mb, because of the lack of coupling. | Coupling of HRES with the ocean began in June 2018 (cycle 45r1). |</p>
<table>
<thead>
<tr>
<th><strong>TC3. 10m wind maximum around a tropical cyclone</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td>For tropical cyclone forecasts with accurate prediction of minimum pressure, the maximum wind speed is underestimated compared to estimates from official tropical wind warned centres. The difference can be partly explained by different wind speed definitions, and also the sub-grid scale nature of a local wind speed maximum. However, it is probably also related to the over-ocean drag parametrisation in cases of extreme wind speeds.</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th><strong>Winds</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>W1. Under-estimation of strong gusts in convective situations</strong></td>
</tr>
<tr>
<td>Although there is a helpful convective contribution in the computation of maximum gusts (as used in direct model output and the EFI), experience has shown that extreme gusts are generally under-represented, particularly when vigorous convection is involved, such as one might see with MCSs or squall lines - eg 60kt gusts or more might be observed when 30-40kt gusts are predicted. This relates to (i) an inability, at current model resolution, to represent the 3-d circulation around convective systems, and (ii) the fact that it is impossible to design an adjustment in the gust computation that will work in all cases.</td>
</tr>
</tbody>
</table>

| **W2. Spurious short-fetch reduction in wind gusts** |
| When a body of water lies downwind of land the 10m wind gust output parameter can exhibit an unrealistic localised reduction over that water, that spans a relatively short distance (perhaps 2 gridlengths). In one case the gust parameter changed from 23m/s over land, to 15m/s over a resolved lake. This issue probably relates to the fact that gusts are computed in part by adding to the mean wind a momentum transport component that depends on the vertical wind shear. It seems that if the shear is small, as can happen in the area just downwind (where roughness is small, sometimes because waves are also small), the reduction in the added component can be less than the concurrent increase in the mean wind, and so the net effect is that the diagnosed gust reduces, unrealistically. So users need to be aware that strong gusts could be underestimated just offshore (lake or sea). Lake Balaton is one area where this effect seems to have been noted. |

| **W3. Winds over mountains underestimated** |
| As some users have reported, wind speeds forecast over mountains (e.g. Norway, Iceland) tend to be too light compared to available observations. Errors can be particularly large when the geostrophic wind is large. 100m wind, available to customers as a standard model parameter, offers a viable and often more accurate alternative for predicting the mean 10m wind speed over mountains. However users must also consider the influence of observation site exposure. |

| **Miscellaneous** |
| **M1. Jumpiness in EFI and SOT, especially at short lead times** |
| A consequence of the re-forecast strategy is that extreme events are sometimes not well sampled. Especially at short lead times, say 1 or 2 days, the 11 members that go up to make the re-forecast can be very similar, and so if the re-forecast dates (twice per week since May 2015) happen to be just before certain extreme events there may be some over-sampling, whilst if extreme events fall in-between the re-forecast dates, there may be some under-sampling. Thus the tails of the model climate (M-Climate) distribution can be jumpy as we move from one lead time to another, and as EFI and SOT depend heavily on these tails, much more than they depend on solutions around the median, they can be jumpy too. |

| **M2. Sunshine duration irregularities** |
| The integrity of this post-processed output parameter is strongly compromised by the radiation timestep in the model (3 hours in ENS, 1 hour in HRES), which because of computational cost is longer than the basic model timestep. This manifests itself in the sunshine duration parameter being (a) an undesirable function of longitude and (b) more generally unreliable. |

| **M3. Sea ice evolution and associated weather** |
| Sea ice cover does not change in any interactive way in the forecasts as we do not have a sea ice model. So none of the following are represented: sea ice formation due to low air temperatures, break up due to wind effects or melting, and advection by currents and winds. In turn this affects weather that relates, such as 2m temperatures over and downwind of, and convection triggered over water but not over ice. Wave model output will naturally also be affected. |

| **Radiation code changes were introduced in cycle 41R2 (March 2016) which markedly reduced the dependence on longitude. Reliability also improved, providing a better match to the WMO sunshine definition. But see also more recent item M12 below.** |

| **Sea ice model introduced operationally in Nov 2016 into ENS with cycle 43r1 (though note that HRES has no sea ice model as yet)!** |
### M4. Very poor SST evolutio near New York

Due to the lack of resolution in the ocean component of the semi-coupled ENS system we are now running (introduced in Nov 2013 with 40R1), and an associated poor handling of the gulf stream wall, there is a major anomalous upward drift in SSTs over and S and E of the New York Bight (which itself lies just SE of New York city), in the first 10 days of the ENS forecasts. The area affected is about the size of England, and the size of the error that develops in 10 days can exceed 10°C.

### M5. 'Hot spots' near to glaciers

When cycle 41R1 was introduced on 12 May 2015 an error began to appear, over certain glaciated/partly glaciated regions (e.g. Iceland, the fringes of Greenland), on 2m temperature products that represent, directly or indirectly, anomalies. Affected fields include EFI/SOT (large positive values). Meteograms with climate (M-Climate too cold) and monthly forecasts (positive anomalies regularly forecast). This error is not a reflection of the absolute forecast values themselves - those should generally be OK - but is instead indicative of an error that was inadvertently introduced into the re-forecast suite. This error makes the 2m temperature forecasts in those re-forecasts, close to glaciers, much colder than they should be, causing the actual forecasts to look like they are indicating strong positive anomalies. Initially, in May, the error was less or non-existent because it was masked by residual seasonal snow cover.

### M6. 'Cold ring' around sea ice after day 10

Since the introduction of 41R1 on 12 May 2015 a ring of cold SST values (~1.8°C), about one gridbox wide, has appeared at the day 10/11 resolution change, along the edges of areas of sea ice. Locally SSTs may suddenly drop by more than 5°C. This is a complex issue but relates to a change in the threshold at which sea ice cover is accepted (it is now 2%, it used to be 20%), the fact that we have to interpolate SST values onto a different grid when resolution changes, and the fact that SST is now set to -1.8°C in gridboxes that include some sea ice. A related complication is the fact that the two-way coupled ocean model runs on a different grid (1 degree). The ice cover threshold change was made to improve the handling of ocean waves in ice-margin zones, and to pave the way for introduction of a full ice model in the future. These advantages are considered to outweigh the 'cold ring' disadvantage. The day 10-15 EFI 2m temperature field can also be affected (showing a band of low values in the ice margin zones).

### M7. Missing islands

A new land-sea mask was introduced with cycle 41R1 on 12 May 2015, in order to improve representativeness. Unfortunately there were some deficiencies in the source dataset, which has meant that a few islands, that should really be there, are no longer present in the IFS. The problems are mainly in HRES. Samoa is the island group that the greatest impact is seen. These issues will clearly reduce the utility of some IFS output, such as meteograms for some islands. For more details, including illustrations, go here. Note that the ocean wave model is not affected.

### M8. Seasonal lakes

In some locations lakes can undergo large changes in areal coverage, seasonally and with further modulation due to anomalous weather types. In the IFS lake areas are fixed, and are configured to match an ESA "GlobCover" dataset, which itself was derived by blending satellite images. So there are two potential sources of lake-cover related errors in the IFS; one is inaccuracies in GlobCover, the other is temporal variations in lake size. In parts of Australia lake cover issues have had an adverse impact on forecasts of cloud cover, temperature, cloud cover and convection, not only in the immediate vicinity but also, via advection, in regions well beyond. Similar problems may also exist in other areas.

### M9. Visibility biases

Visibility is a very difficult parameter to predict with a global model, a problem exacerbated somewhat by there being no aerosol emissions/transport. Since introduction of this diagnostic variable in May 2015 characteristics have been investigated, over Europe. Impressions of overall performance were positive, though the following general issues have been noted:

- a) visibility in radiation fog tends to drop a bit too low, on average (e.g. 50m when 100m would be better)
- b) radiation fog formation tends to occur bit too late, and fog clearance a bit too early (e.g. 1-3 h typical bias in each case)
- c) background visibility (when no fog or precipitation) seems to be a bit too high overall
- d) hill fog seems to be under-represented (though this may relate to model orography limitations)
- e) visibility tends to be too low during rainfall
- f) visibility tends to be too high during snowfall

Problem alleviated slightly when ocean model in ENS went from 1.0 to 0.25 deg resolution in Nov 2016.

The error has now been corrected. Affected re-forecasts will not themselves be rerun, although newly created re-forecasts should, from data times in early July 2015 onwards, be correct. This means that the mentioned issues slowly went away between early July and mid August 2015, as the fraction of the re-forecasts that were contaminated steadily reduced.

In March 2016 (cycle 41R2) the resolution change was moved to be at day 15, and so this issue no longer affects the twice daily ENS forecasts.

Corrected in March 2016, with the introduction of cycle 41R2.

Through acquisition of more accurate lake-cover datasets - e.g. from forecast users - it may be possible to alleviate some of these problems. Non-interactive seasonal variation of lake extent is also being considered.

Ther model upgrade introduced in October 2021 specifically targeted items (a), (e) and (f). Performance is much better in these scenarios, with biases substantially reduced. Getting the details correct in radiation fog (a) remains challenging however. See here for more information.
| M10. Sea ice in the Baltic | Sea ice cover analyses in the Baltic are ‘discretized’. In other words certain ice configurations can appear often, others not at all. For example much of the Gulf of Finland tends to be relatively uniformly covered with sea ice of a set concentration, or just open water. In turn this is because satellite data, which feeds the Met Office OSTIA product used in the IFS, has particular difficulties in sensing ice where the water salinity is reduced by incursions of freshwater, as in the Baltic. This results in there being very few satellite sea ice pixels in the Baltic - the ones there are a long way from land - and in turn the information from these pixels gets copied into data-free areas nearby. |
| M11. Stratospheric biases | IFS representations of the stratosphere suffer from various biases, which may be negatively impacting upon the skill of some longer range tropospheric predictions. These include different temperature biases at different levels, excess moisture ‘leakage’ from the troposphere into the lower stratosphere and unrealistic springtime breakdown of the polar vortex in the seasonal forecasting system (SEAS5). The representations of ozone and (large amplitude) gravity waves are also problem areas. Model changes in cycle 47r1 (June 2020), in data assimilation and in the vertical interpolation methodology, have together substantially reduced stratospheric biases in the IFS. For example temperature biases in the analysis, above the 100hPa level, were reduced by up to 50%. |
| M12. Systematic overestimates of “sunshine duration” | The IFS “sunshine duration” parameter can, in some regions and some scenarios, provide large overestimates of sunshine duration relative to what is measured by conventional instrumentation. This can be in spite of there being, at the same time, a correct representation of the downward solar radiation in the IFS. Examples of this behaviour have been noted in summer time in Switzerland. The way in which cloud optical properties are handled in the IFS is suspected to be the main cause of this discrepancy. ECMWF may be able to resolve this in future. A consequence of the new moist physics scheme introduced in October 2021 was that larger amounts of cloud were forecast than hitherto. Sunshine amounts reduce as a result, which may alleviate this problem. See here for more information. |
| M13. Convective Inhibition (CIN) | A weakness in ECMWF’s CIN diagnostic has been identified. Sometimes values are much too high. The current advice is to not use this field for operational purposes. ECMWF re-formulated and thoroughly tested new code for computing CIN, and this revision was introduced operationally with cycle 47r1 in June 2020. |
| M14. In thick fog relative humidity drops and temperature rises. | A bug introduced in cycle 47r3 in October 2021 has resulted in a tendency for 2m dewpoint and relative humidity (RH) values to sometimes drop to unrealistically low values once fog has been predicted/diagnosed in model output. This process is most apparent when dense fog is forecast (e.g. visibility < 100m). This is clearly unphysical and indeed wrong - RH should be close to 100% in such a situation. As these errors occur we sometimes also see a spurious increase in 2m temperature, with near surface superadiabats on model vertical profiles. In one NW Europe HRES case in Jan 2021, at one site, where visibility was forecast to be ~40m, the 2m temperature and dewpoint were respectively 0.5C and -10C. Both should have been ~ -2C. This issue was investigated as a matter of priority. The cause was found to be positive feedback between two interacting and imperfectly represented mixing processes in the new moist physics scheme. A fix was implemented operationally with the 06UTC cycle on 22 Feb 2021. |